Examinations in Cardiology I - Hemodynamics

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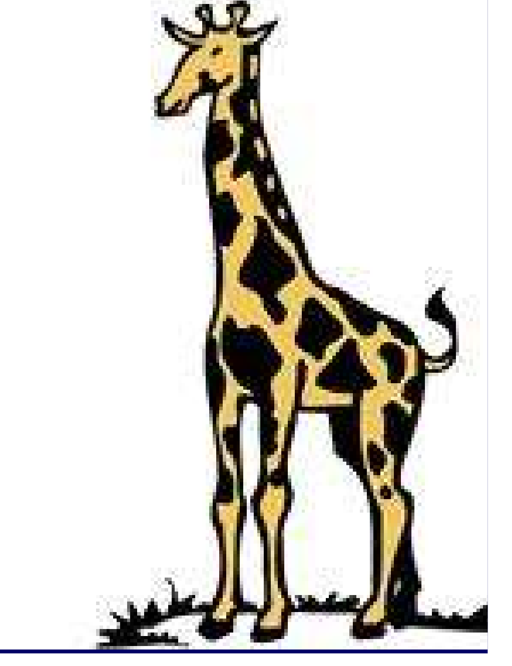
(Physical problem/ description)

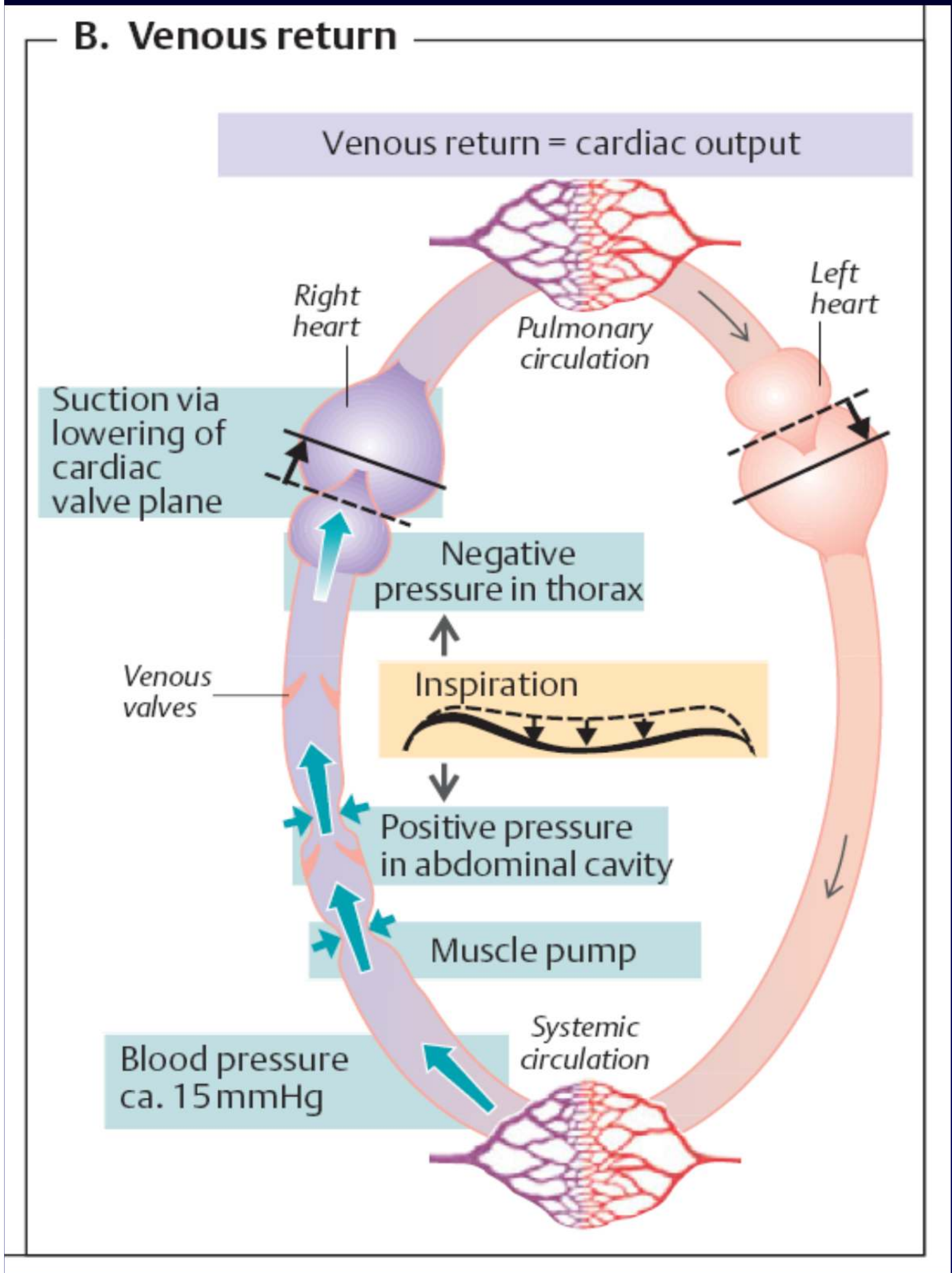
Problem of hydrostatic pressure and a a giraffe.

Tallest of all mammals/ herbivores.

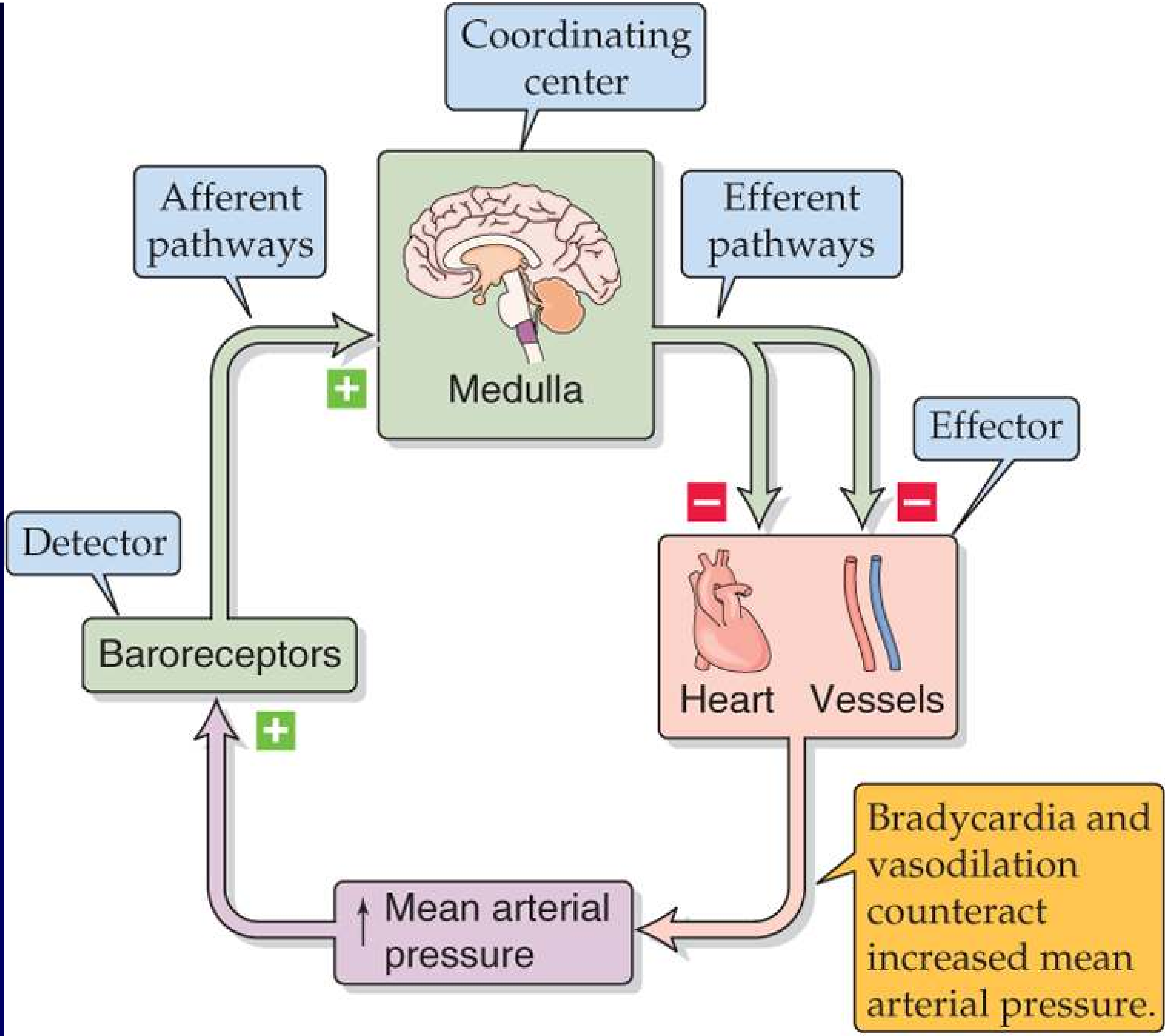
Males: height from 4,8 to 5,5 m (weight 900 kg).

What about their brain perfusion?
80 cmH2O (= 60 mmHg)?



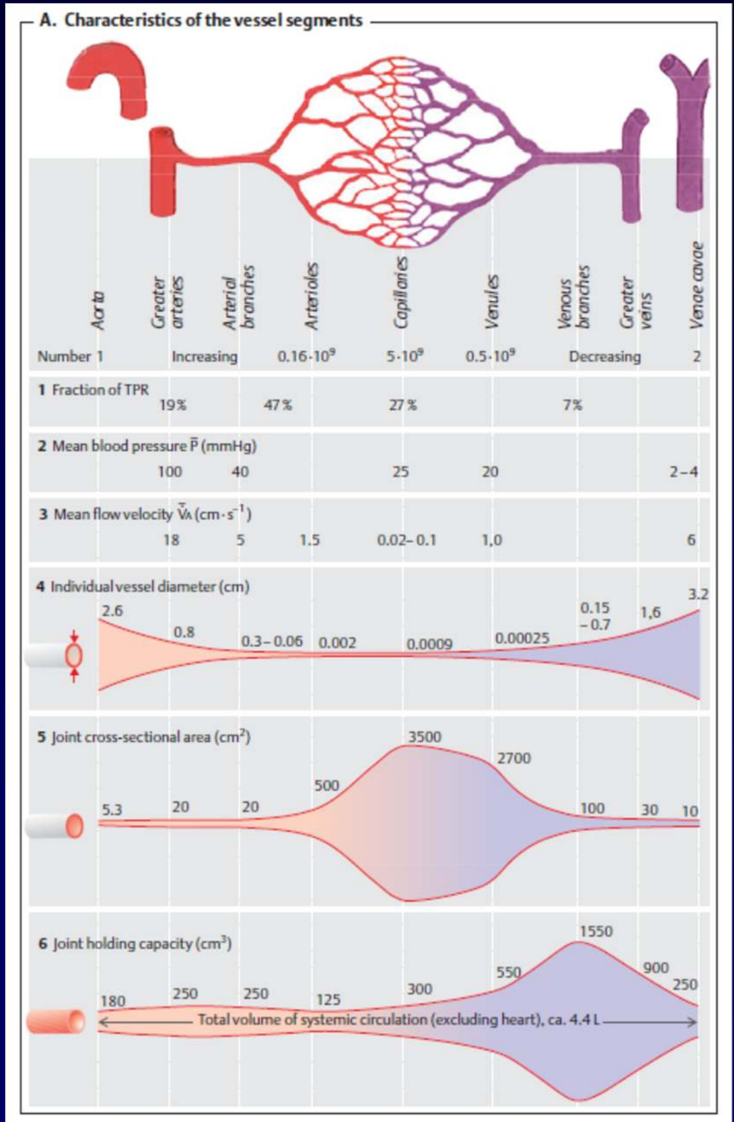


Venous valves/ + ventilatory movements



Boron & Boulpaep: Medical Physiology, 2nd Edition.

Arteries, veins and capillaries

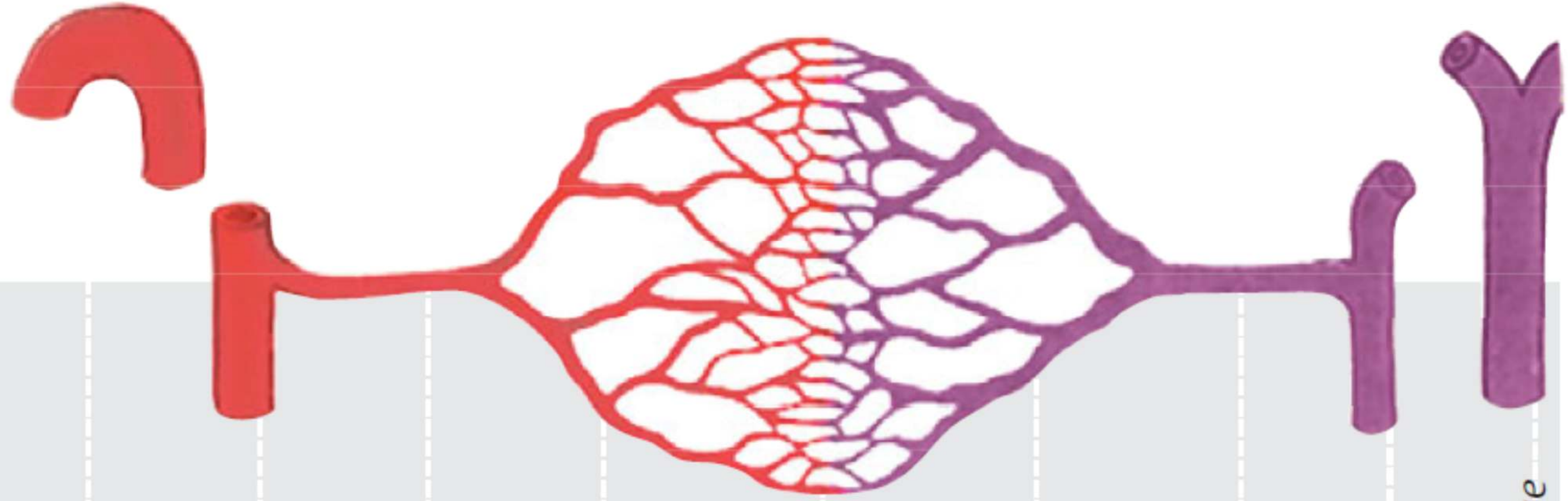


$\Delta P = Q.R$
Hydraulic version
Of the Ohm's law

This is the systemic part.
(The other is the pulmonary part.)

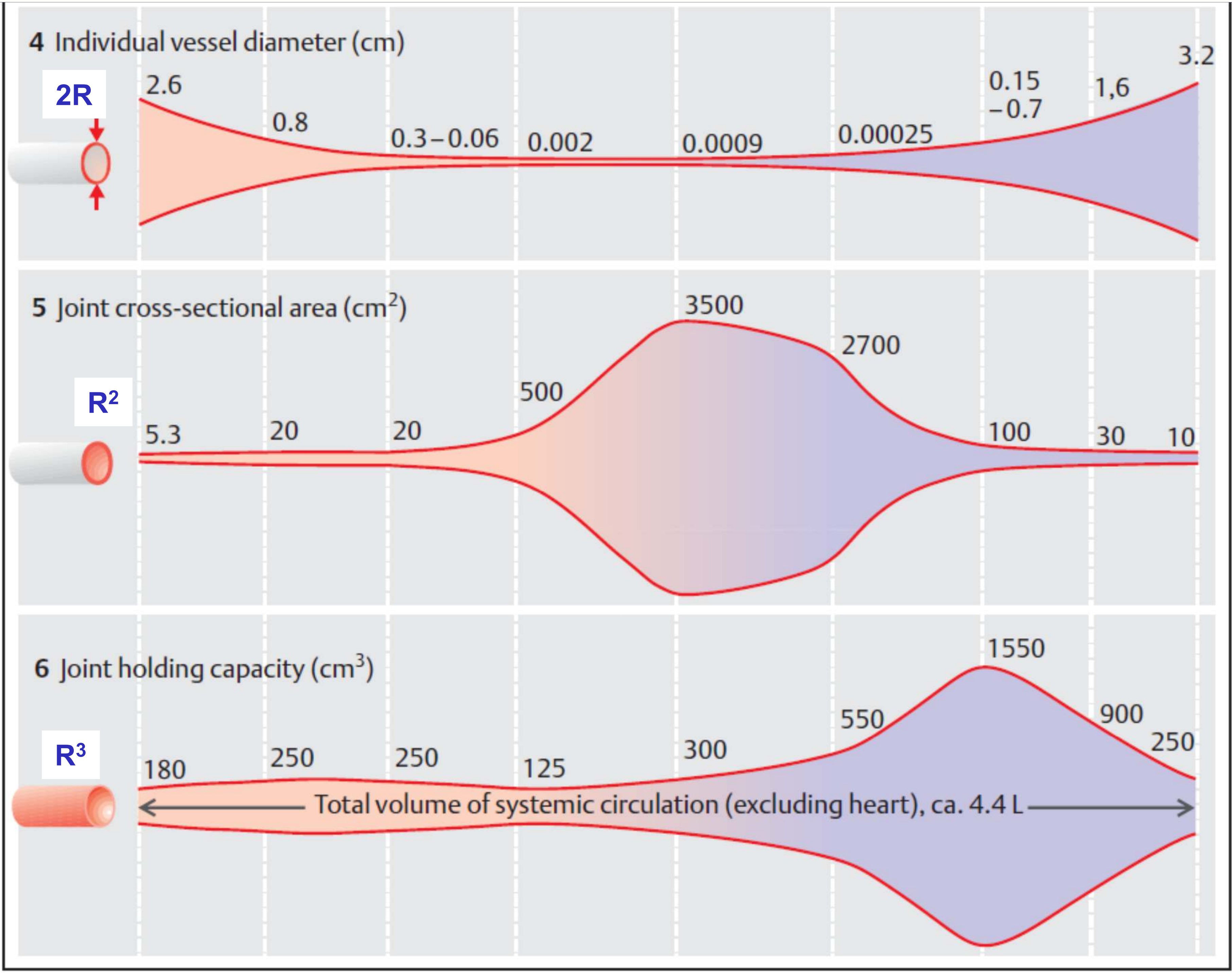
$P_0 > P_1 > P_2 > P_3$, atd.

A. Characteristics of the vessel segments



	Aorta	Greater arteries	Arterial branches	Arterioles	Capillaries	Venules	Venous branches	Greater veins	Venae cavae
Number	1	Increasing		$0.16 \cdot 10^9$	$5 \cdot 10^9$	$0.5 \cdot 10^9$	Decreasing		2
1 Fraction of TPR		19%		47%	27%		7%		
2 Mean blood pressure $\bar{P}$ (mmHg)		100	40		25	20			2–4
3 Mean flow velocity $\bar{\dot{V}}_A$ ($cm \cdot s^{-1}$)		18	5	1.5	0.02–0.1	1,0			6

TPR (=Total Peripheral Resistence)



4 Individual vessel diameter (cm)
2R
2.6
0.8
0.3–0.06
0.002
0.0009
0.00025
0.15 –0.7
1,6
3.2
5 Joint cross-sectional area (cm2)
R2
5.3
20
20
500
3500
2700
100
30
10
6 Joint holding capacity (cm3)
R3
180
250
250
125
300
550
1550
900
250
Total volume of systemic circulation (excluding heart), ca. 4.4 L

(Physical description)

1) Ohm's law

$$\Delta P = Q.R$$

2) Energy

$$E/\ V = \rho gh + \Delta P + (1/2)\rho V^2$$

3) Pulsatile flow

$$_{dot}Q = V_{stroke} f_{HR}$$

(Physical description)

Mean pressure, $P_{sys} > P_{mean} > P_{dia}$

$P_{mean} = (1/3)\ P_{sys} + (2/3)\ P_{dia}$

(Energy calculations:

$P_{mean} = (4/5)\ P_{sys} + (1/5)\ P_{dia}$)

(Macro)-circulation in 4 linearised equations, „physical model",

V ...[Liter] volume
$\dot{Q}$ ...[Liter/sec] flow
R_P ...[torr.sec/Liter] pulmonary resistance
R_S ...[torr.sec/Liter] system resistance
p_AS...[torr] pressure arterial systemic
…et cetera

1. Frank-Starling law
2. Ohm's law (Poiseulle law simplification)
3. Compliance
4. Continuity equation

$$\dot{Q} = k_\mathrm{LH}\overline{p}_\mathrm{SV} = k_\mathrm{RH}\overline{p}_\mathrm{PV}$$

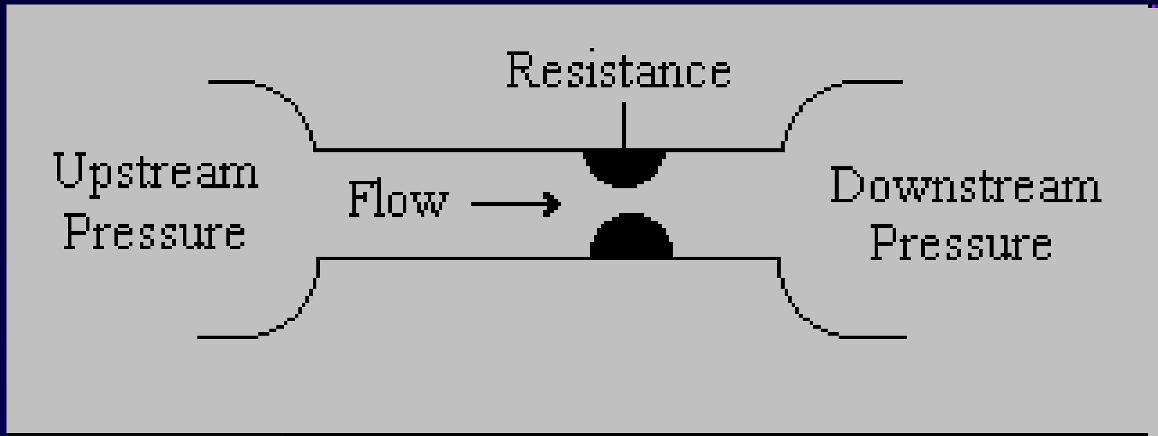
$$I = \frac{U}{R}, \dot{Q} = \frac{(\overline{p}_\mathrm{IN} - \overline{p}_\mathrm{OUT})}{R}$$

$$V_\mathrm{VS} = c_\mathrm{VS}\overline{p}_\mathrm{VS}$$

$$\sum V_i = V_\mathrm{TTL}$$

(1) Ohm (Poiseulle) law

$\Delta p = Q.R$



Pressure-Flow-Resistance Relationship in a Blood Vessel

Blood flow in a blood vessel is equal to the pressure difference along the vessel divided by the vascular resistance.

Flow = (Upstream Pressure - Downstream Pressure) / Resistance

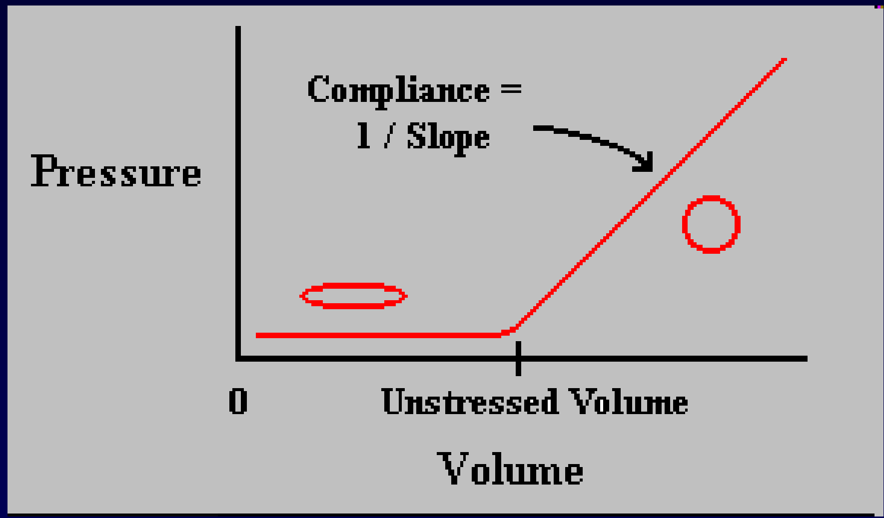
Vascular *conductance* is the reciprocal of vascular resistance. The pressure-flow relationship becomes

Flow = (Upstream Pressure - Downstream Pressure) * Conductance

Typical units for vascular conductance are (ml/min) / mmHg.

(2) Compliance

Blood vessels tend to collapse at low volumes. Internal pressure is equal to external pressure, which is often at or close to zero relative to atmospheric pressure.
As additional volume is added, a critical volume is reached where any added volume causes the internal pressure of the vessel to increase. This critical volume is called the *unstressed* volume. Unstressed volume is usually denoted by V0 or V_0.
Vascular compliance is the reciprocal of the slope of the pressure-volume relationship at volumes greater than unstressed volume. The physical units for compliance are typically ml/mmHg.
Approximate compliance values (ml/mmHg) for an adult male are



Pressure-Volume Relationship in a Blood Vessel

Arteries	1.5
Veins	80
Whole-Body	140

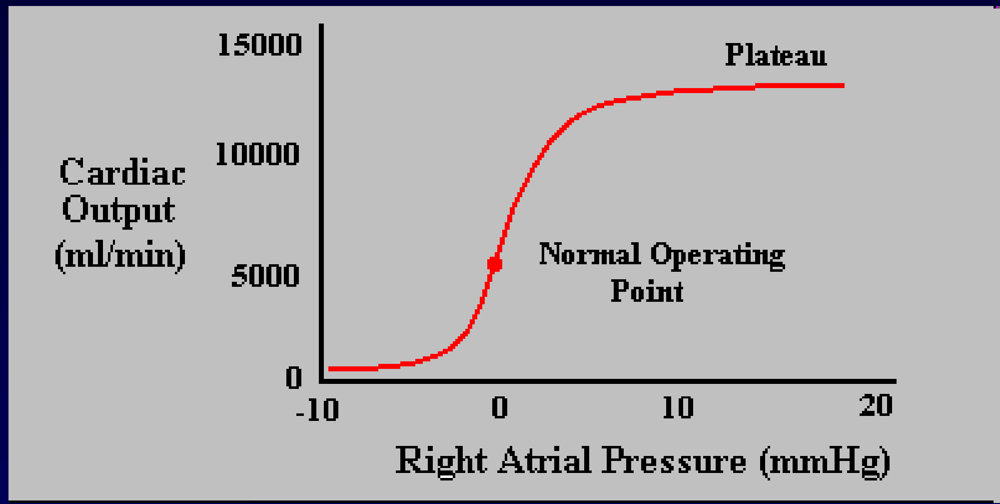
P	Pressure (mmHg)
V	Volume (ml)
V0	Unstressed Volume (ml)
C	Vascular Compliance (ml/mmHg)

Equations describing the pressure-volume relationship:

$$P = 0 \text{ when } V <= V0$$

$$P = (1/C) * (V - V0) \text{ when } V > V0$$

(3), Frank-Starling law



The Frank-Starling relationship may describe the right heart alone, the left heart alone, or the right heart, pulmonary circulation, and left heart combined. This last case is described here.

The Frank-Starling relationship describes the blood pumped by the heart-lung compartment, cardiac output, in terms of the filling pressure, right atrial pressure.

(4), continuity equation

$$\boxed{\sum V_i = V_{\mathrm{TTL}}}$$

VB = V0 + VAS + VVS + VAP + VVP

…, ☺,

(Macro)-circulation in 4 linearised equations, „physical model“,

V ...[Liter] volume
$\dot{Q}$ ...[Liter/sec] flow
R_{P} ...[torr.sec/Liter] pulmonary resistance
R_{S} ...[torr.sec/Liter] system resistance
p_{AS}...[torr] pressure arterial systemic
…et cetera

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$$I = \frac{U}{R}, \dot{Q} = \frac{(\overline{p}_{\mathrm{IN}} - \overline{p}_{\mathrm{OUT}})}{R}$$

$$V_{\mathrm{VS}} = c_{\mathrm{VS}}\overline{p}_{\mathrm{VS}}$$

$$\sum V_i = V_{\mathrm{TTL}}$$

William Harvey (1578-1657)

- Hemodymamics
- Discovery of blood circulation and heart function (published 1628)
- This theory was fully accepted after discovery of pulmonary capillaries (Marcello Malpighi - 1661).

Principles of hemodynamics evaluation

- Measurement and evaluation of volume and pressure provide information about the cardiovascular system function.

- The cardiovascular system transports ***volume*** (blood) between individual body compartments

- Blood ***pressure*** is necessary to maintain proper blood flow
  - to form pressure gradient between heart and the periphery
  - to overcome the peripheral resistance.

Ohm's law

Q (flow) = ΔP (pressure gradient) / R (resistance)

Principles in hemodynamics evaluation

Blood volume and pressure influence heart and vessels anatomy

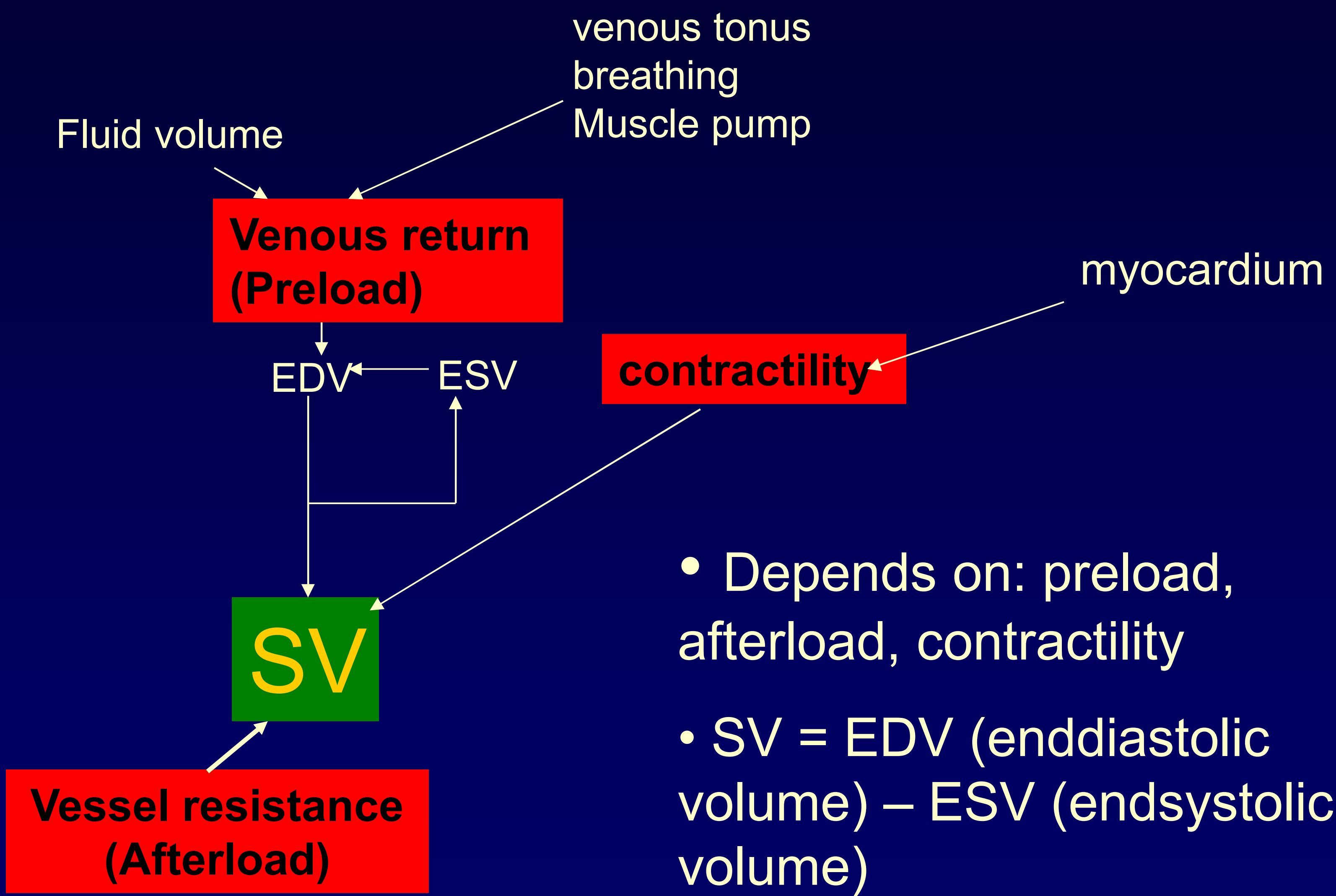
- changes which are important for the function of cardiovascular system
  - heart muscle dilatation
  - heart muscle hypertrophy
  - Increase in vessel resistance (organ, systemic, temporary, permanent)

Volume

Stroke (systolic) volume (SV)

- blood volume ejected from ventricle during systole

Stroke Volume

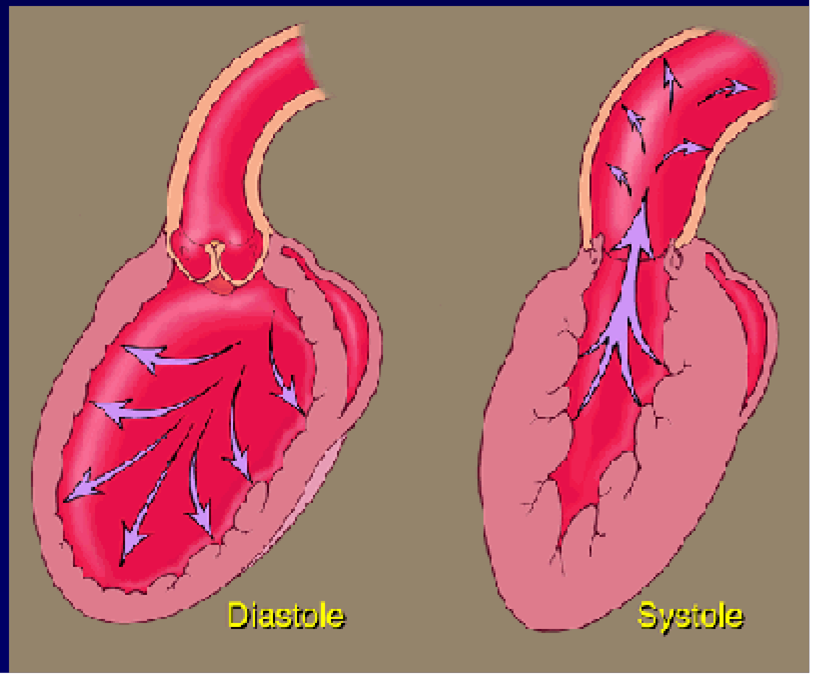


- Depends on: preload, afterload, contractility
- SV = EDV (enddiastolic volume) – ESV (endsystolic volume)

Ejection fraction (EF)

EF = SV / EDV

SV – systolic volume
EDV – endiastolic volume



Ejection fraction (EF)

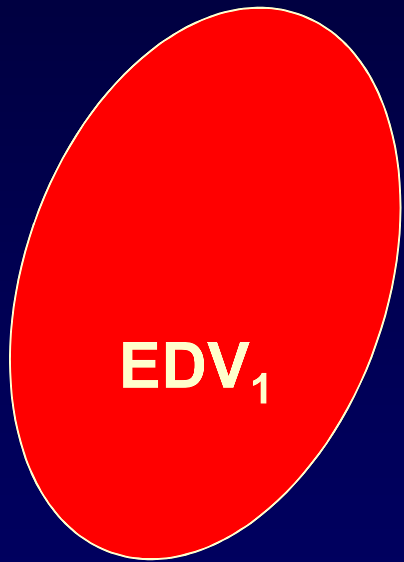
- Basic parameter for evaluation of the ***systolic function*** of the heart

- Decreased: *decreased contractility (CHD = coronary heart disease), heart failure, valvular diseases*, …
- Increased: *hypertrofic cardiomyopathy*

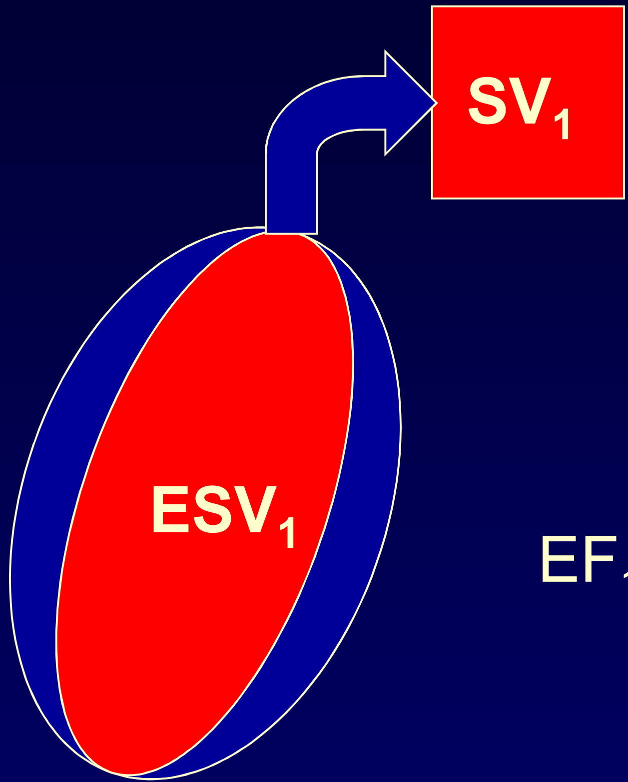
Ejection fraction (EF)

Normal values:
50–55 % and more
increased e.g. due to sympathetic stimulation and other inotropic action
40 % and less in systolic dysfunction

Measurement:
most commonly by ***echocardiography***,
also by isotope methods

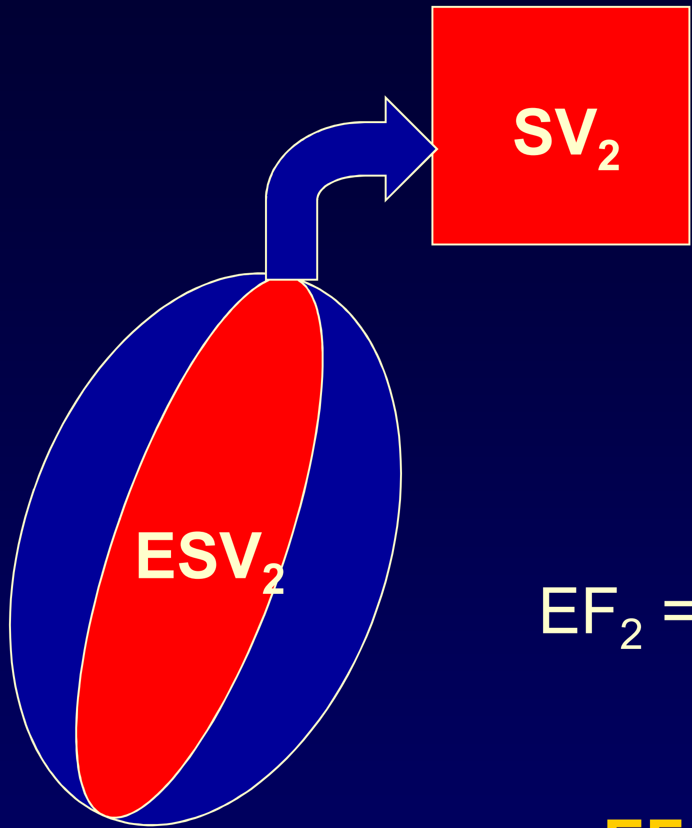


End of diastole 1



$EF_1 = SV_1/EDV_1$

End of systole 1

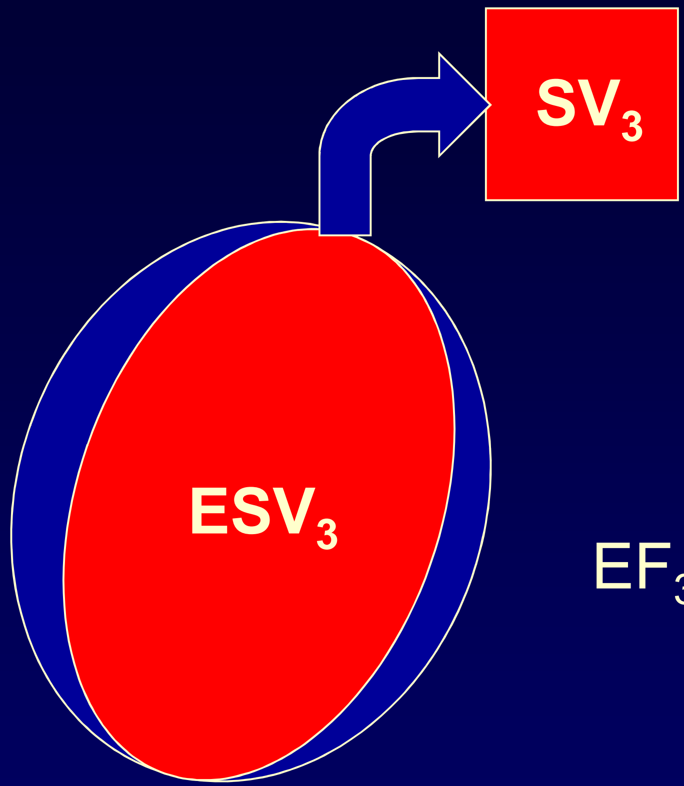


$EF_2 = TO_2/EDV_2$

$EF_2 > EF_1$

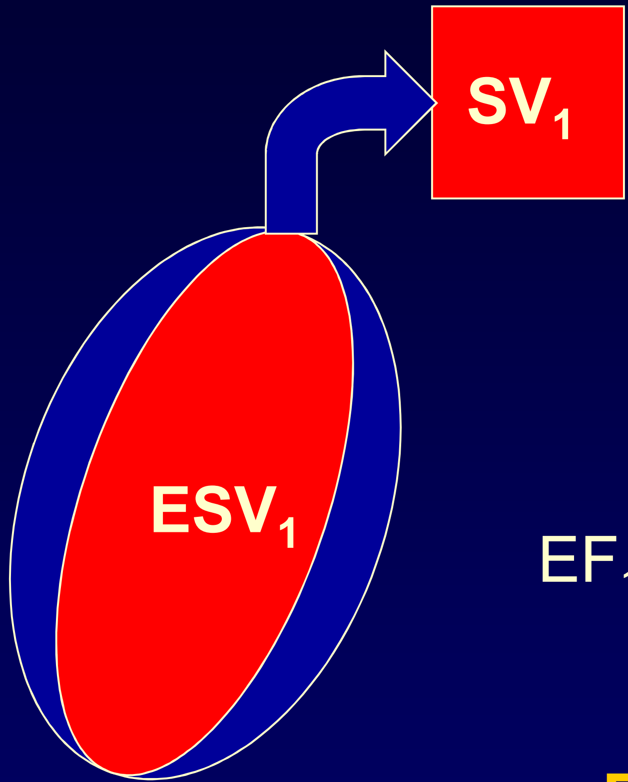
End of systole 2

End of diastole 2



$EF_3 = SV_3/EDV_3$

End of systole 3



$EF_1 = SV_1/EDV_1$

$\mathbf{EF_1 > EF_3}$

$\mathbf{SV_1 = SV_3}$

End of systole 1

Calculations and comments on EF

- Left ventricle has at the end of the diastole volume of 145 mL. Cardiac output is 4,8 L/min. Heart rate is 90/min.

Calculate and comment EF

- EDV = 145 ml
- SV = ?
- CO = 4800 mL/min
- HR = 90/min
- SV = CO / HR = 4800 / 90 = 53,3 mL
- EF = 53,3 / 145 = 0,37 (37 %)

Calculate and comment EF

- Cardiac output is nearly normal
- Mild tachycardia
- Increased preload
- Decreased EF

Decreased effectivness of the systole is compensated by the increase of preload and tachycardia

Cardiac output, cardiac index

CO = HR × SV

(HR = heart rate, SV = stroke volume)

- Normal values: 4–7 L/min

CI = CO/body surface

- Normal values: 2.8 – 4.2 L/m^2

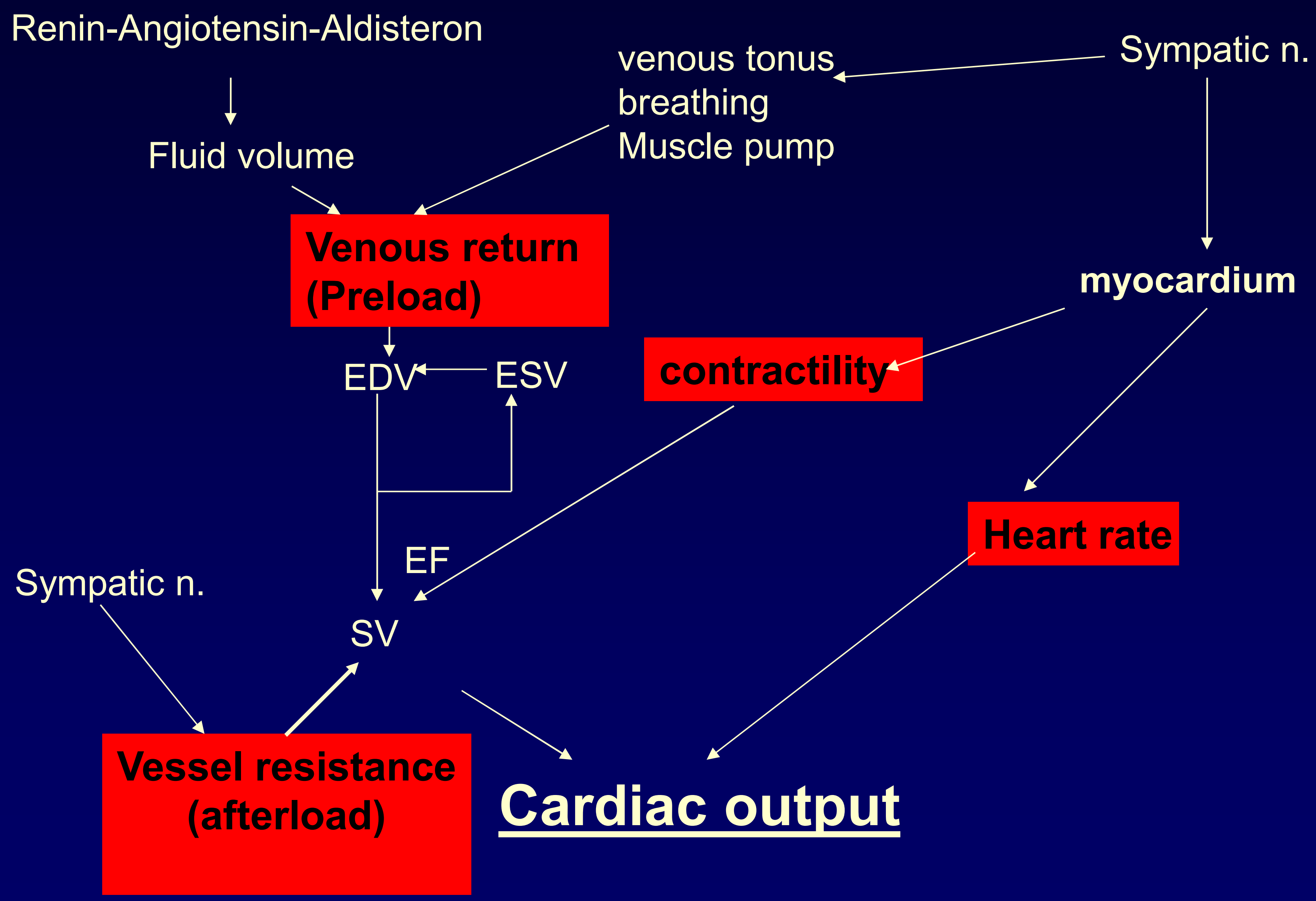
Measurment:

- Thermodilution (standard) – Swan-Ganz catheter
  - Fick Principle (oxygen consumption/ CO2 production)
- Noninvasive methods (Echo with Doppler)

Thermodilution method

- The applies indicator dilution principles using temperature change as the indicator
- A known amount of solution at a known temperature is injected rapidly into the right atrial lumen of the catheter.
- This cooler solution mixes with and cools the surrounding blood, and the temperature is measured downstream in the pulmonary artery by a thermistor embedded in the catheter.
- The resultant change in temperature is then plotted on a time-temperature curve

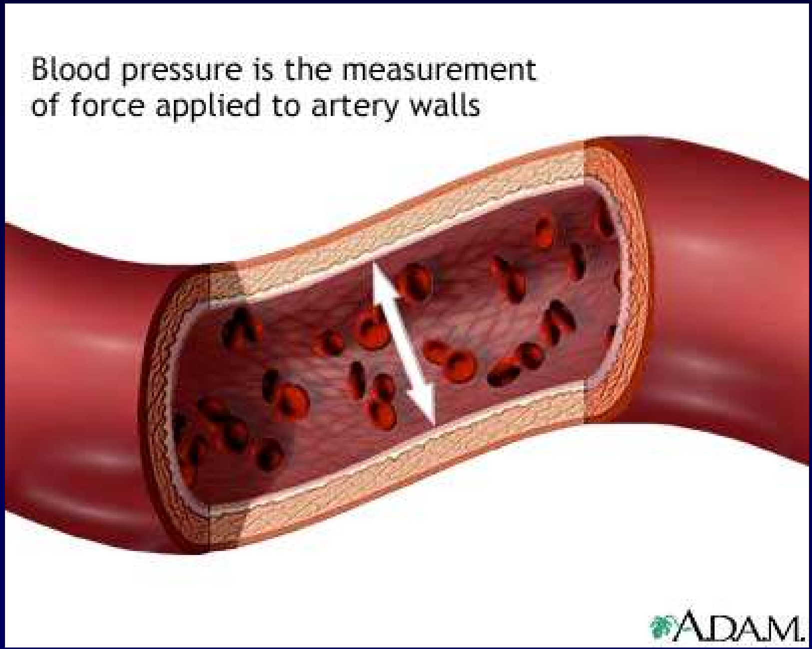
Systolic Function of Heart



Pressure

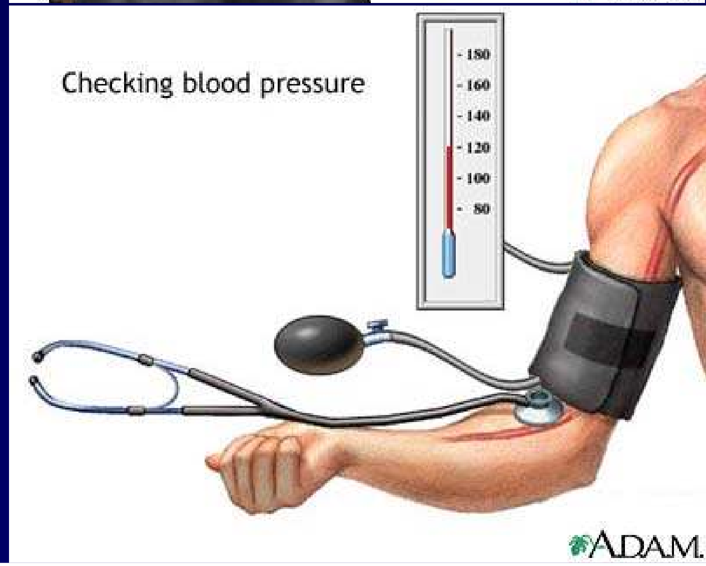
Blood Pressure

- Measured in millimeters of mercury (or kPa), within the major arterial system of the body
- Systolic pressure
  - maximum blood pressure during contraction of the ventricles
- Diastolic pressure
  - minimum pressure recorded just prior to the next contraction



Blood Pressure

- The blood pressure is usually taken with the patient seated using standard blood pressure cuff
- Additional information may be gained by checking the patient in the lying and standing positions
  - Systolic blood pressure should not drop more than 10 mm Hg, and diastolic pressure should remain unchanged or rise slightly.



Systemic BP

- *systolic*: heart function
- *diastolic*: peripheral resistance
- mean pressure
- pressure amplitude

- *hypertension, hypotension*

Interpretation of Blood Pressure Measurements in Individuals 18 Years of Age and Older

Diastolic pressure (mm Hg)	**Category**
<85	Normal
85-89	High normal
90-104	Mild hypertension
105-114	Moderate hypertension
>115	Severe hypertension
Systolic pressure (mm Hg) (when diastolic < 90)	**Category**
< 140	Normal
140-159	Borderline isolated systolic hypertension
>160	Isolated systolic hypertension

Pressures in the heart

Atria

- Pressure practically depends on the pressure in the ventricles if the valves are intact
- *Pressure gradients (atrium – ventricle)*
  - valves open, the pressure in the atrium and ventricle is equal in diastole
  - difference originates due to *valve stenosis*
  - the gradient reflects the tightness of stenosis

Pressures in the heart - *Ventricles (chambers)*

Diastole

- during filling of the ventricles the pressure increases, the increase depends on compliance of the ventricle and in normal heart the increase is only weak

Systole:

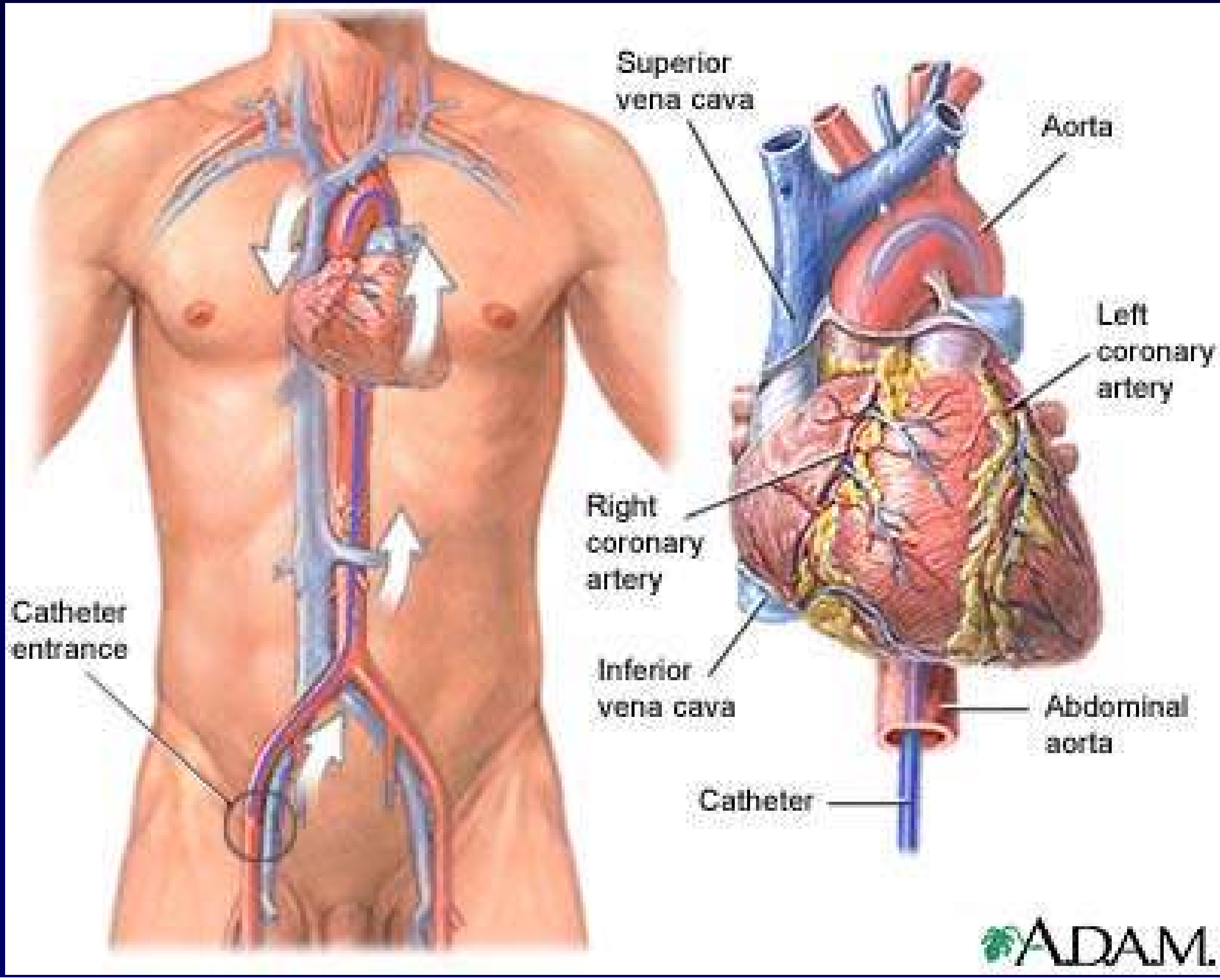
- pressure depends on heart contraction and pressure in aorta/ in pulmonary artery

Invasive measurement of BP

- **pressure measurements in separate heart cavities**
- **wedge pressure – end-diastolic pressure**
- **pressure gradients**
- **cardiac output**
- **blood for oxygen saturation**
- Injection of contrast dyes for angiography
- biopsy

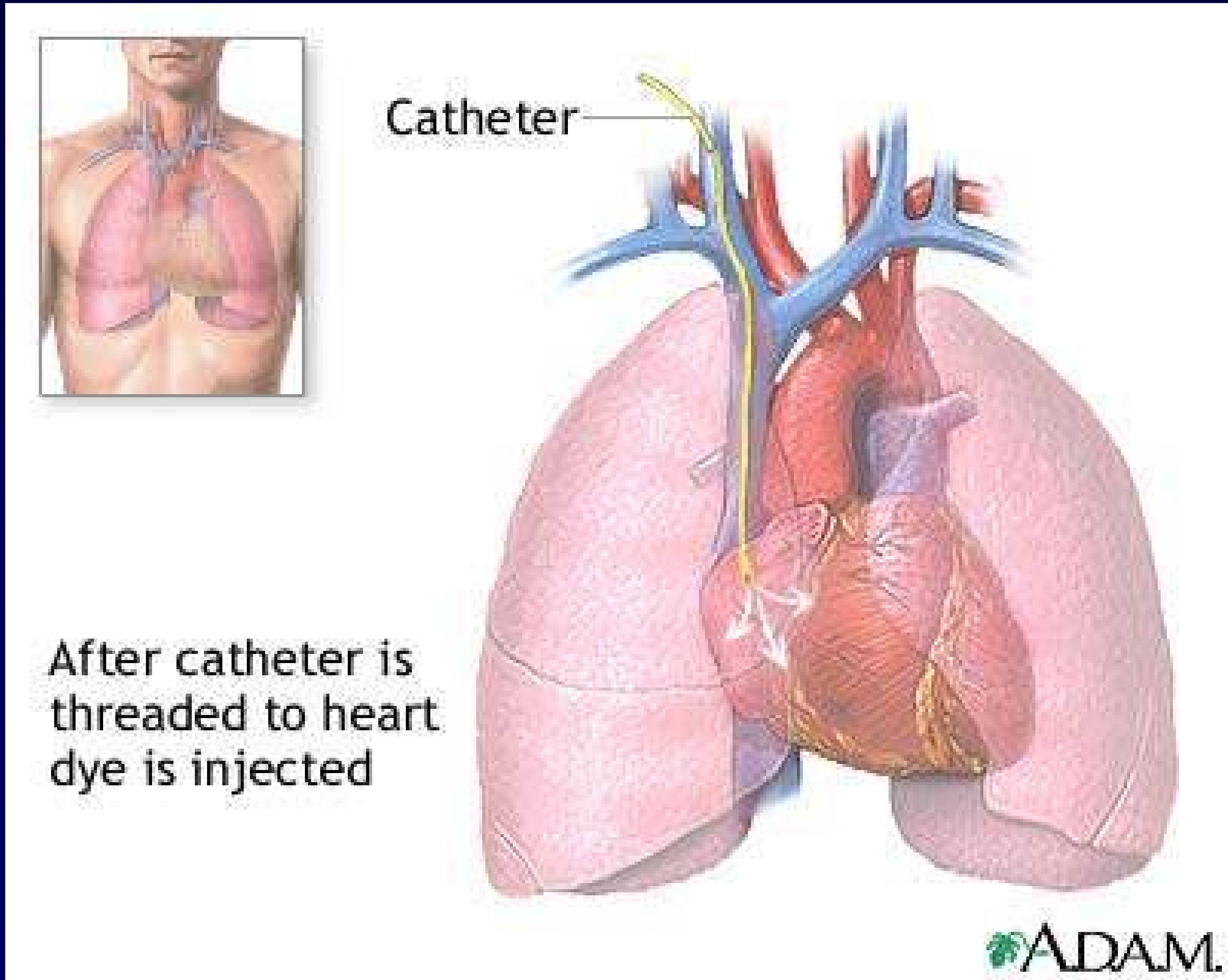
Invasive measurement of BP

Cardiac Catheterization (A. Femoralis –> Aorta)



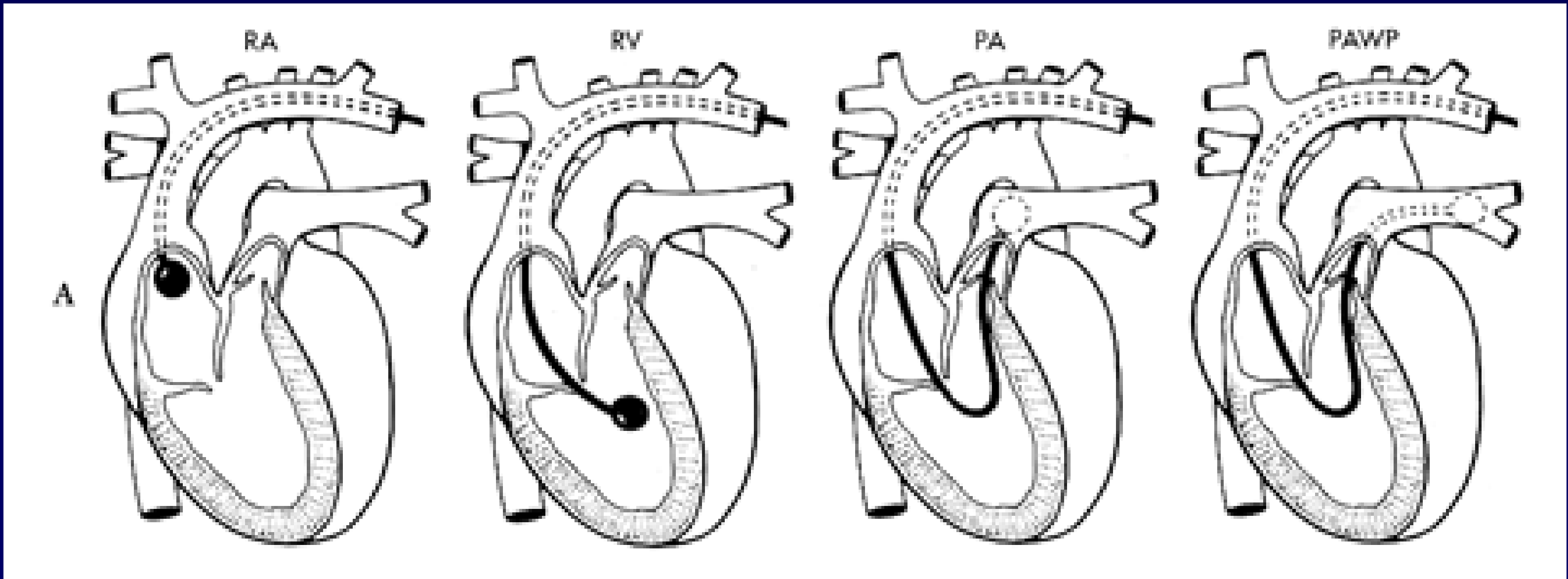
Invasive measurement of BP

Cardiac Catheterization (V. cava – RA – LV – A. Pulmonaris)

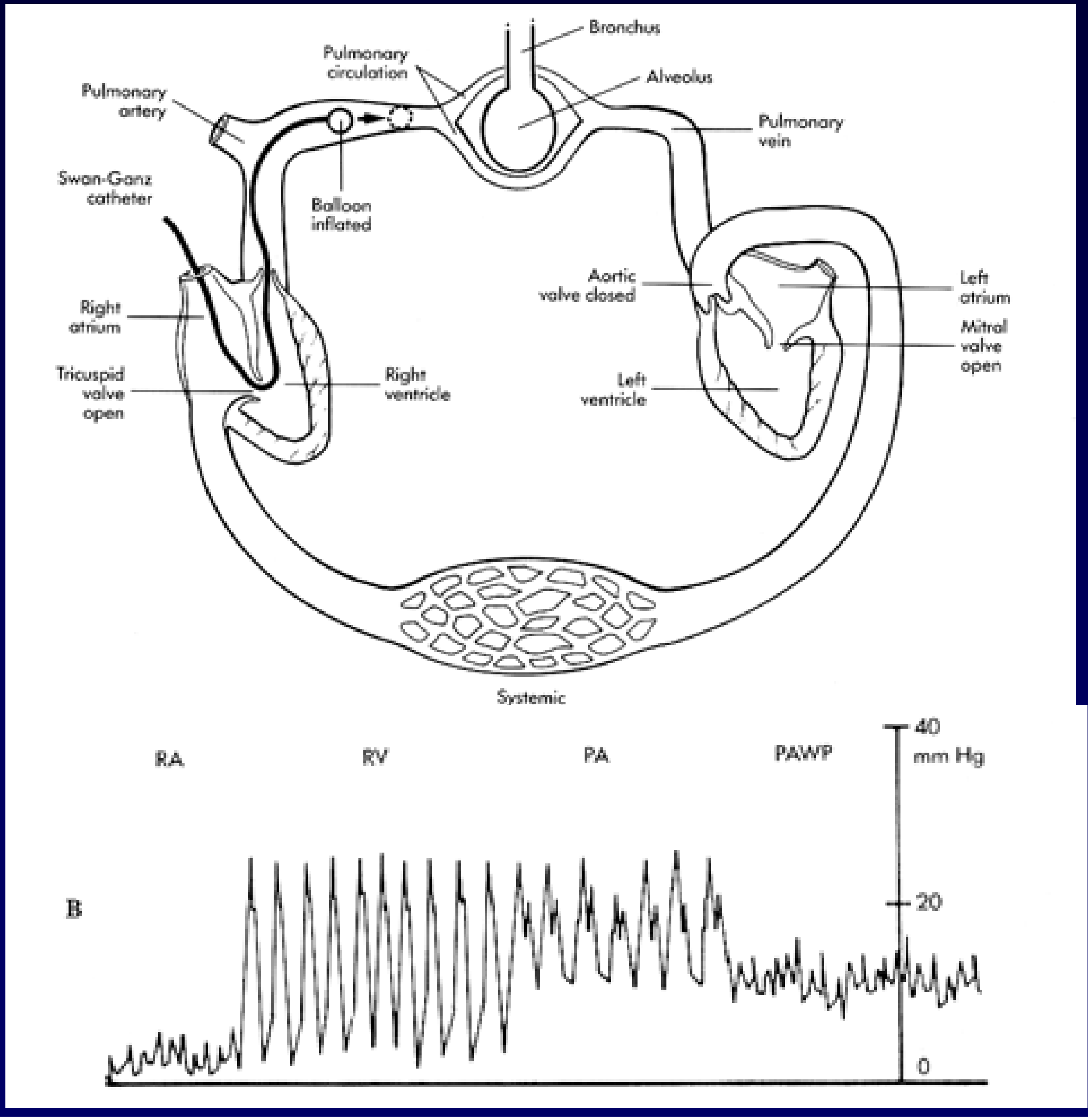


Heart catheterization

- Swan-Ganz catheter position in heart
  - Right atrium (RA)
  - Right ventricle (RV)
  - Pulmonary artery (PA)
  - Pulmonary artery wedge pressure (PAWP)



Pressure tracing during catheterization by Swan-Ganz catheter



PCW

- reflects the pressure in left atrium / ventricle (in absence of mitral stenosis)
- increase in
  - *left heart failure*
  - *mitral stenosis*

right atrium – RA
right ventricle (RV)
pulmonary artery (PA)
PAWP

End-diastolic pressure

- the pressure in the ventricle at the end of diastole
- depends on ***filling*** (volume, preload) and ***myocardial wall properties*** (compliance)

Normal values: 6-12 mmHg

Measurement:

- performed as (pulmonary capillary) ***wedge pressure*** during catheterization
- P(A)WP – pulmonary (artery) wedge pressure *or* PCWP – pulmonary capillary wedge pressure

Central venous pressure (CVP)

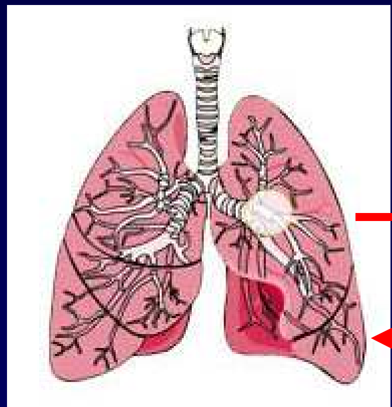
- The pressure of blood in the right atrium
- Swan-Ganz catheter or other
- <u>Normal values</u>: 2-8 mm Hg
- Monitoring of systemic volume filling
- CVP indirectly indicates the efficiency of the heart's pumping action (EDP RV, if not tricuspidal stenosis)
- Decreased due to *hypovolemia*,
- Increased due to *hypervolemia*, right heart failure, tricuspidal stenosis

Pressure values

- pulmonary artery systolic pressure is 15 to 30 mmHg
- pulmonary artery mean pressure is 9 to 17 mmHg (normal < 20 mmHg)
- pulmonary artery diastolic pressure is 0 to 8 mmHg
- pulmonary capillary wedge pressure is 5 to 12 mmHg (mean <12)
- right atrial pressure is 0 to 8 mmHg

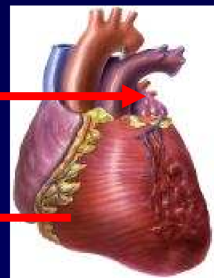
Pressures in pulmonary circulation

systolic /diastolic/ mean/ **borderline**



left atrium **1-5 (up to 12)** mm Hg

vv. pulmonales

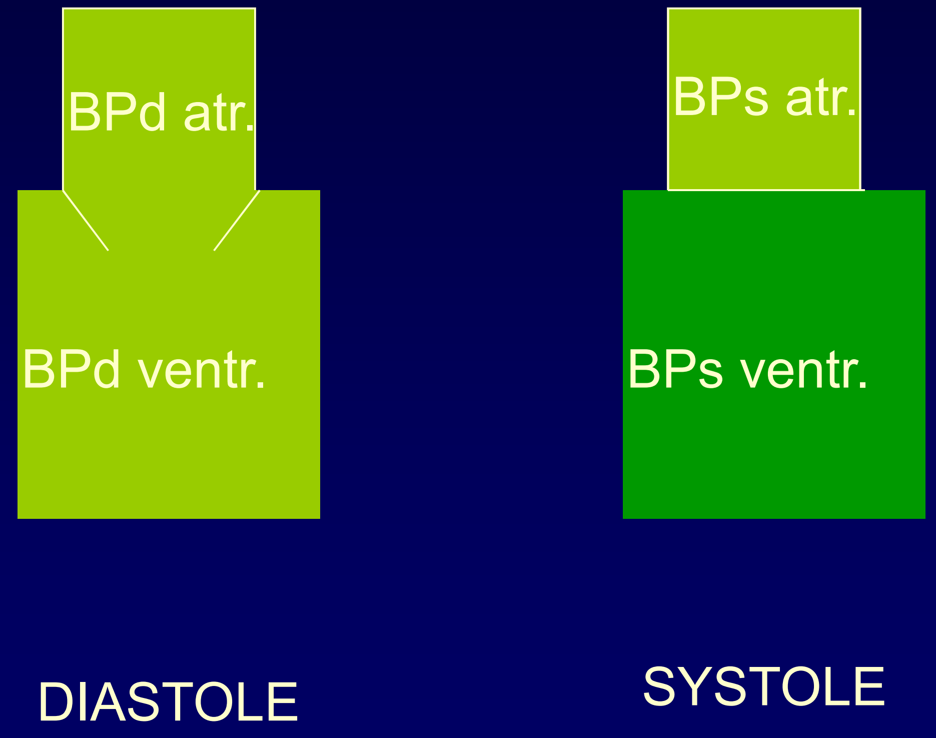


a. pulmonalis: **20 (30)/ 12/ 15 (20)**

right ventricle
20/1

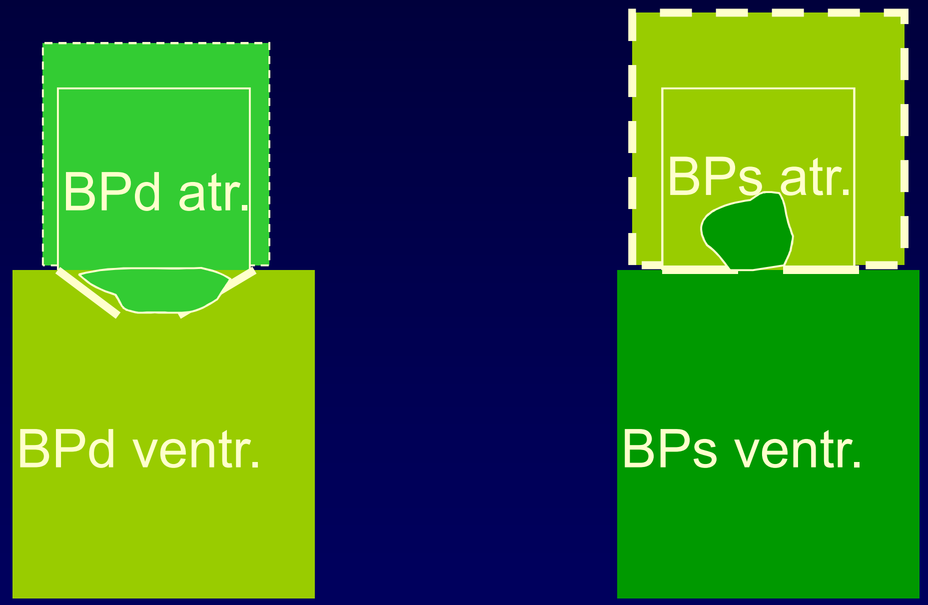
lung capillaries
$\approx$ **7-8**

Pressures in atrium and ventricle



BPd atrium = BPd ventricle

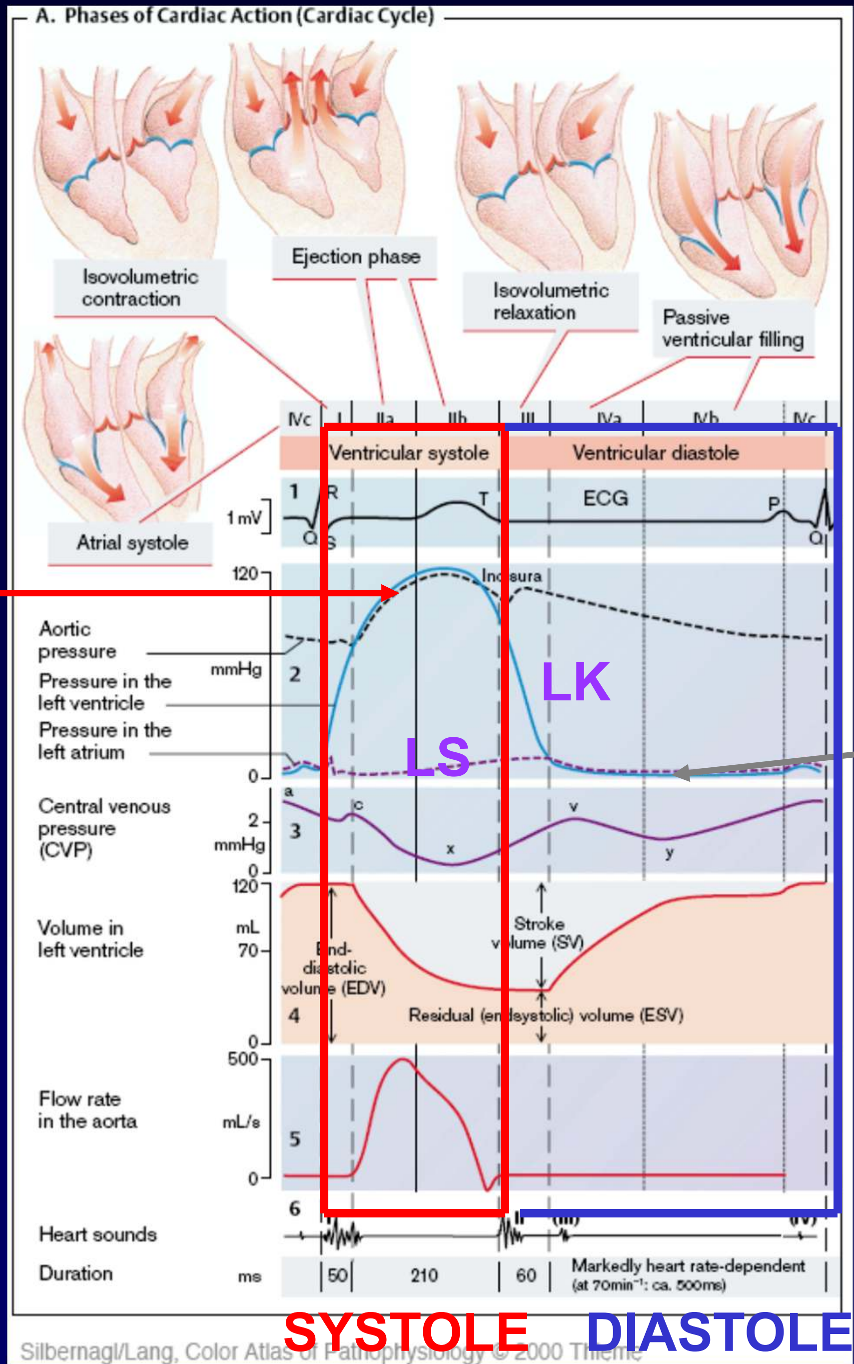
STENOSIS **REGURGITATION**



DIASTOLE SYSTOLE

BPd atrium >BPd ventricle

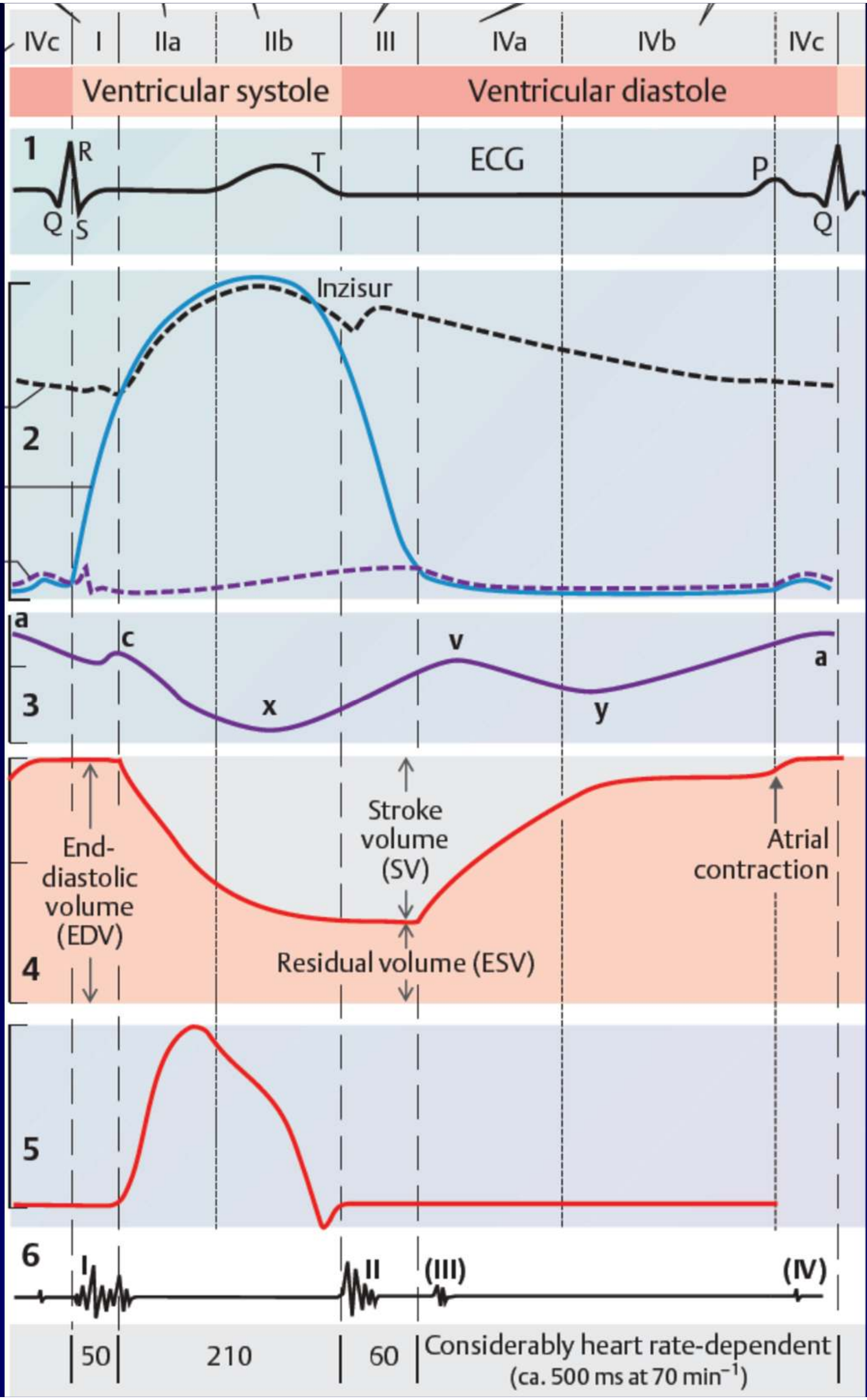
equal pressure
ventricle-aorta
in systole



aorta

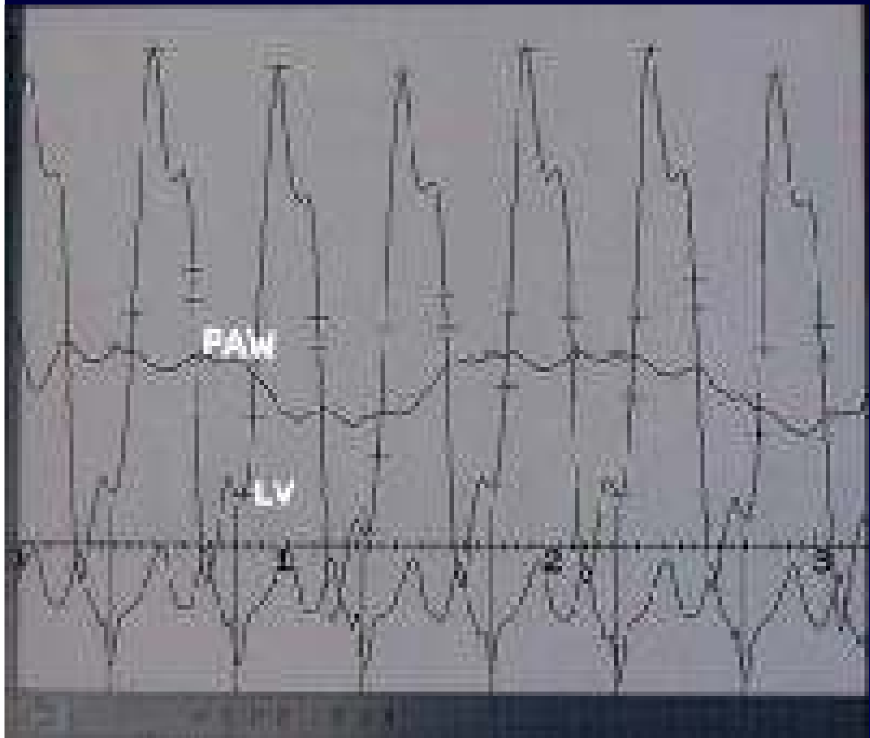
equal pressure
ventricle-atrium
in diastole

Wiggers diagram



Pressures in heart valve diseases

Mitral stenosis

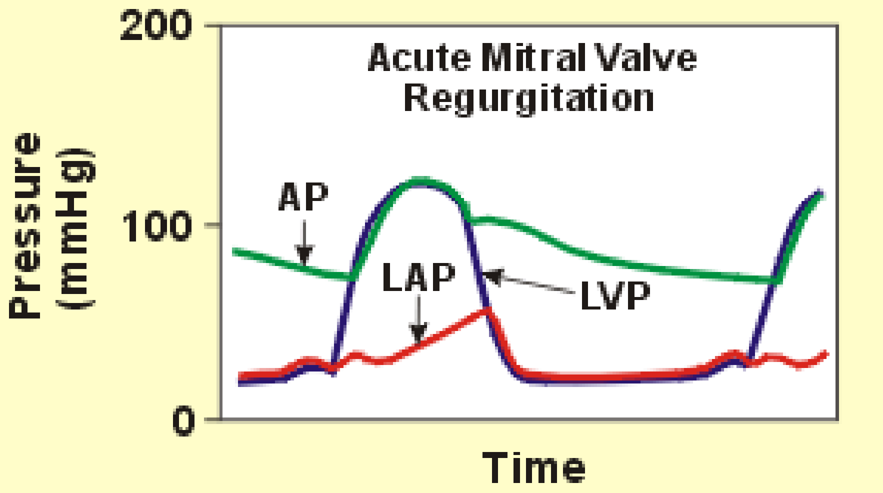


- Simultaneous recording of pressures in the pulmonary artery wedge position (PAW) and the left ventricle (LV)
- large gradient in diastole across the mitral valve. The PAW pressure is markedly elevated.
- Increased pressure in LA improves diastolic flow to LV, LA hypertrophies etc.

- Increased PAW may lead to pulmonary edema

Pressures in heart valve diseases

Mitral regurgitation



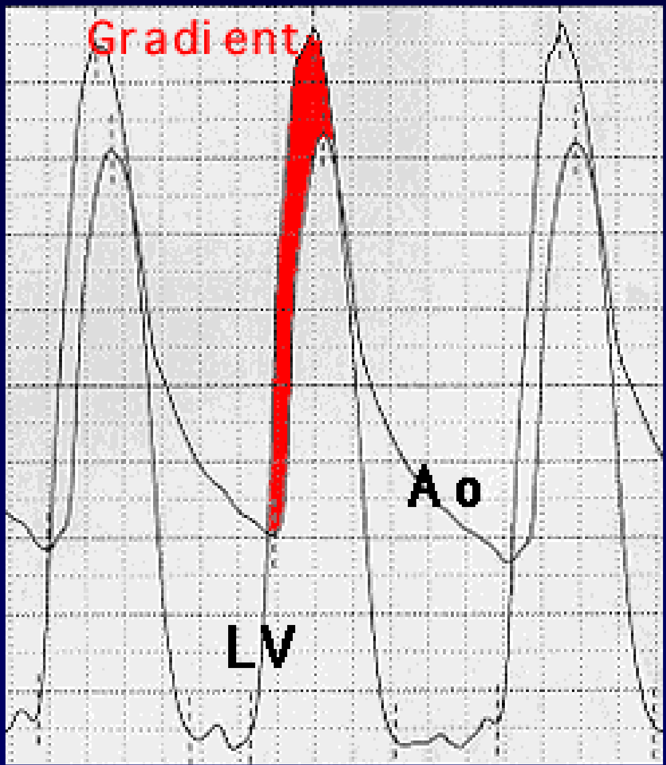
During ventricular contraction(systole), the left ventricle ejects blood back into the left atrium as well as into the aorta, thereby increasing LAP, particularly the v-wave. *Abbreviations:* LAP, left atrial pressure; LVP, left ventricular pressure; AP, aortic pressure.

- increase of pressure in LA during ventricle contraction (part of the blood returns to the atrium)

LA dilation and hypertrophy

Pressures in heart valve diseases

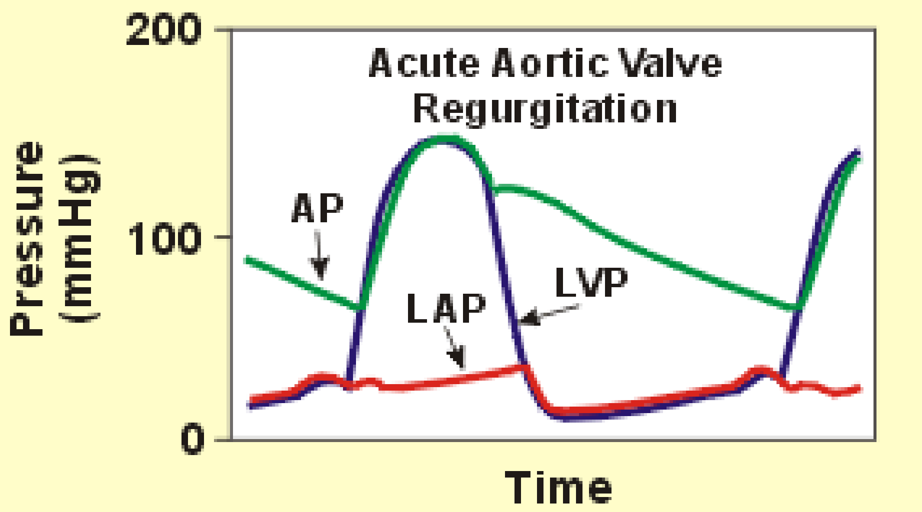
Aortic stenosis



- due to stenosis the pressure in LV increases and becomes higher than pressure in aorta (Ao)
- pressure gradient results (normally both pressure peaks equal)
- important hypertrophy of LV

Pressures in heart valve diseases

Aortic regurgitation



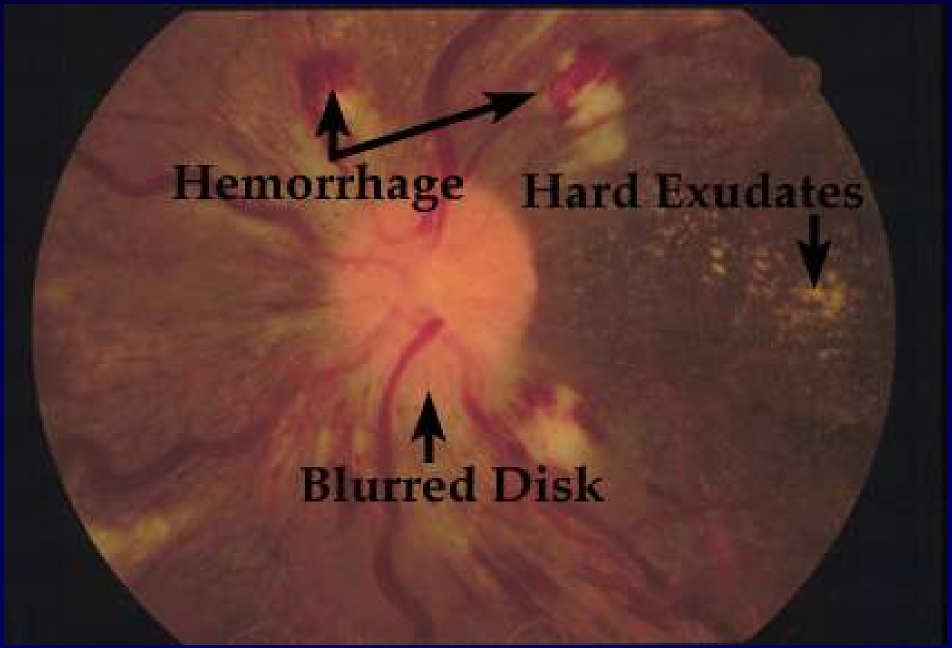
During ventricular relaxation, blood flows backwards from aorta into the ventricle. Aortic pulse pressure and LAP increase.
Abbreviations: LAP, left atrial pressure; LVP, left ventricular pressure; AP, aortic pressure.

- due to backward flow the aortic pressure declines more rapidly
- to compensate (to maintain normal mean pressure) systolic pressure increases
- increased pressure amplitude

Case Study – KVS1

- M 23 yr., admitted to the hospital for malignant hypertension.
- DM from 8 yr. of age fail to take insulin and diet
- fail to take anti-hypertension medication
- 1 wk. before the admission was tired, blurred vision, vomiting.
- 12 h before the admission speech failure
- BP 220/140, No orthostatic
- Edema of lower extremities

Ophthalmologic evaluation: bilateral edema of papilla with hemorrhages and exudates, arterial vasoconstriction.



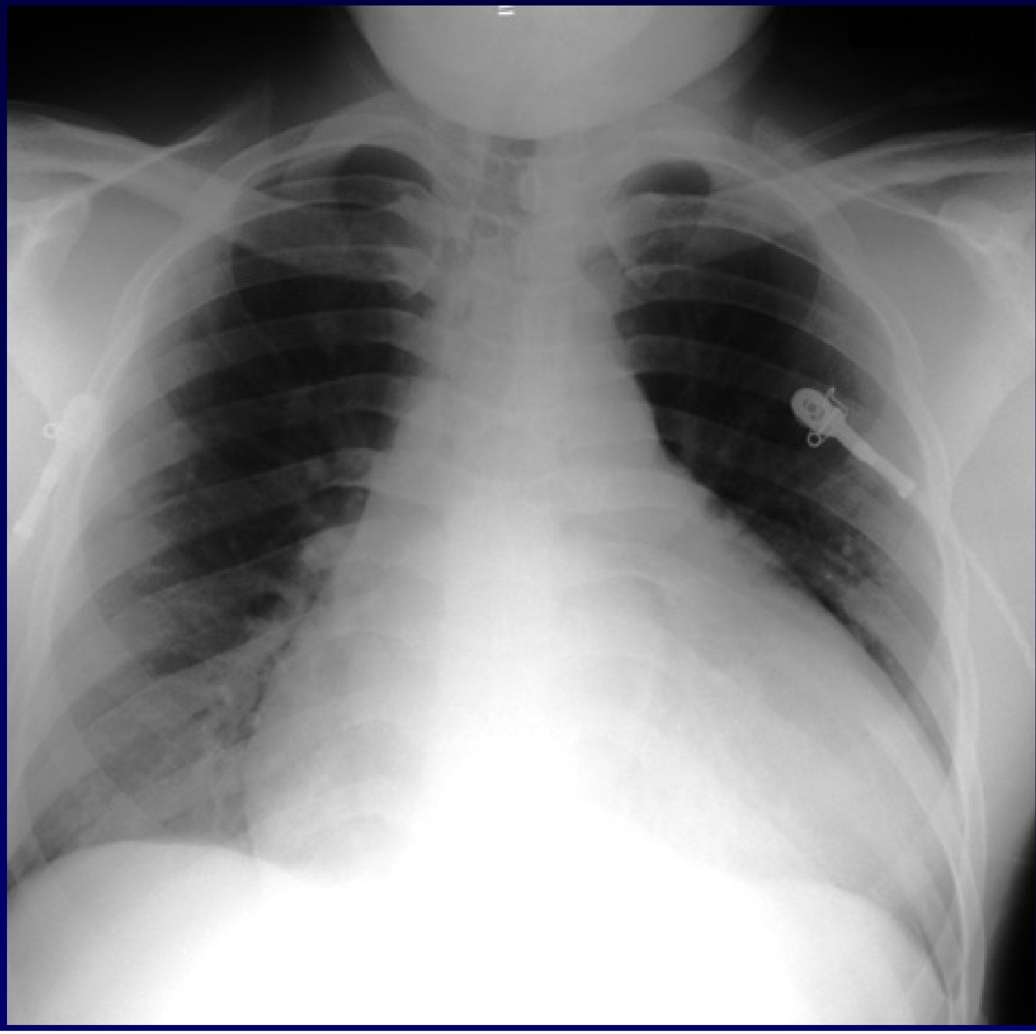
Hypertensive retinopathy (grade IV)

Note the hard exudates in white, the hemorrhages in red, and the blurred disk margin. This is grade four hypertensive retinopathy.

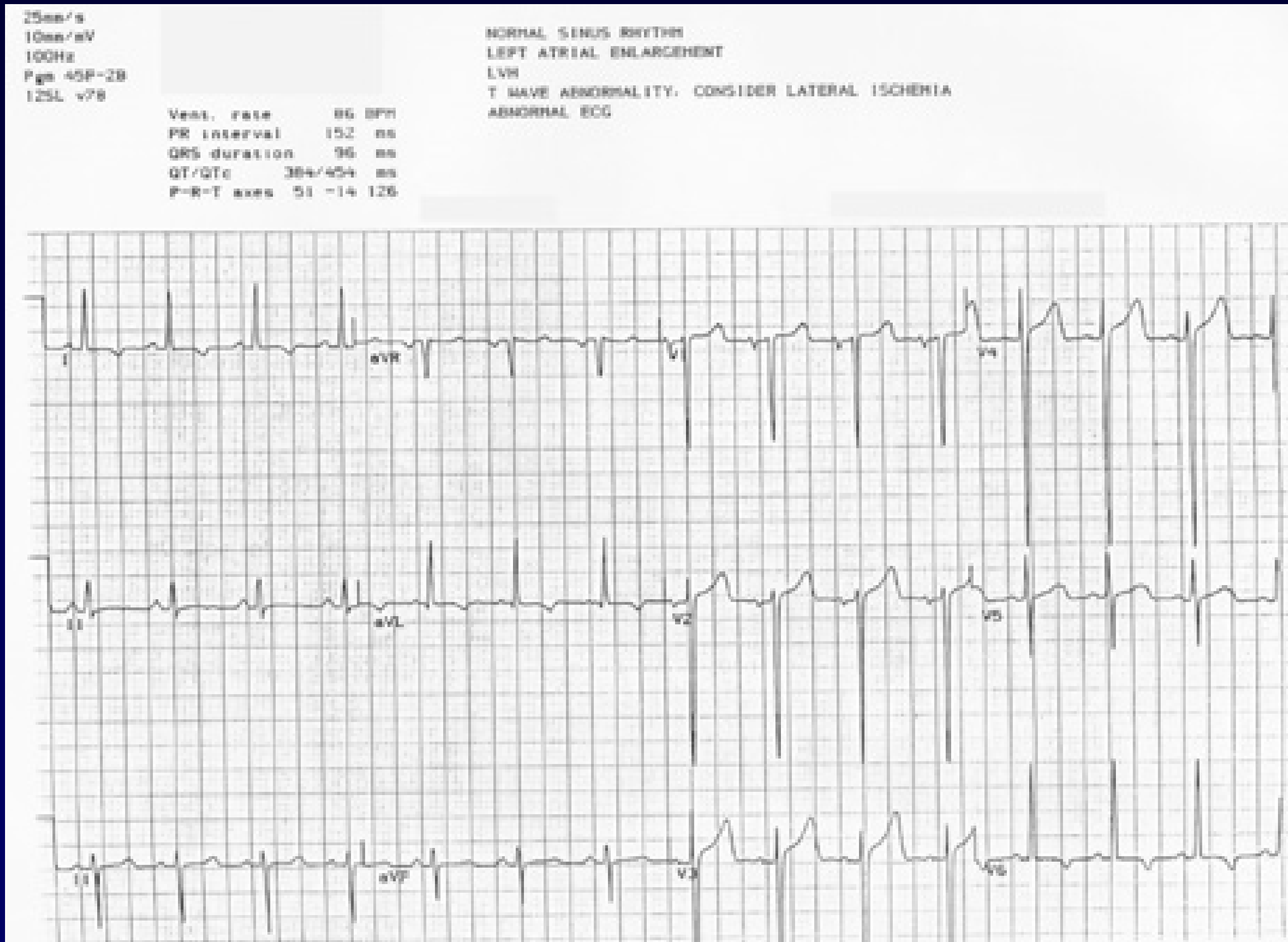
Laboratory

- - hyperkaliemia
- - low bicarbonates
- - creatinin 20.3 mg/ dl (high)
- - proteinuria
- - hematuria (40- 50 RBC per high power field.)

Chest X-ray: enlarged heart - cardiomegaly



ECG: hypertrophy of LV



EKG: Deep QRS waves on anterior chest leads which illustrate left ventricular hypertrophy

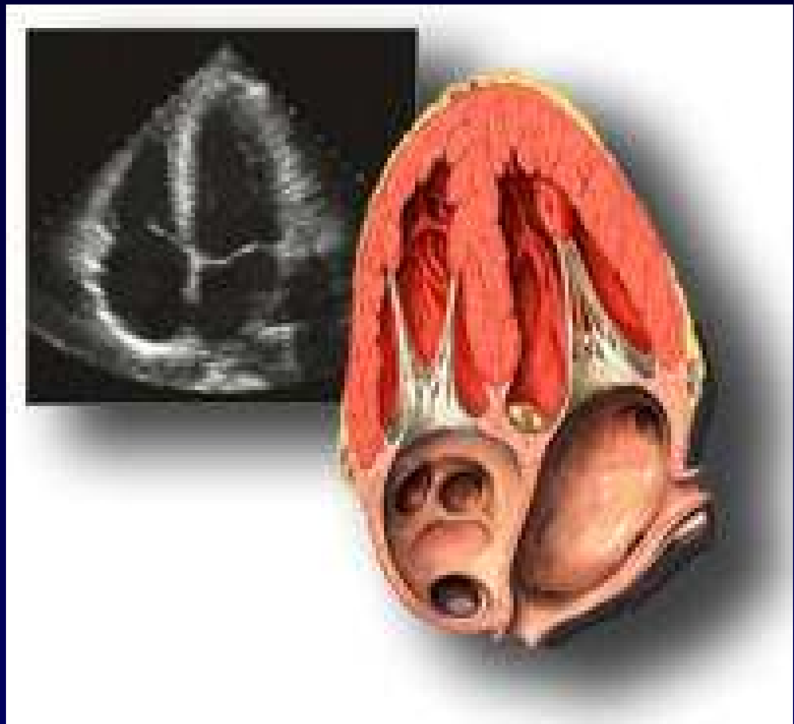
- Diagnosis:
  - hypertension crisis
  - kidney failure
  - Target Organ Damage (Heart hypertrophy, kidney failure, Retinopathy, Cerebro-vascular disease)

- Therapy:
  - I.V. nitroprusside
  - hemodialysis (kidney transplantation)

Imaging methods

- Ultrasound – Echo
- Chest X-ray
- Angiography - Coronarography
- MRI – Magnetic resonance imaging
- CT – computer tomography
- PET (positrone emission tomography – evaluation of heart metabolism
- Radioisotope methods

Ultrasound – Echo



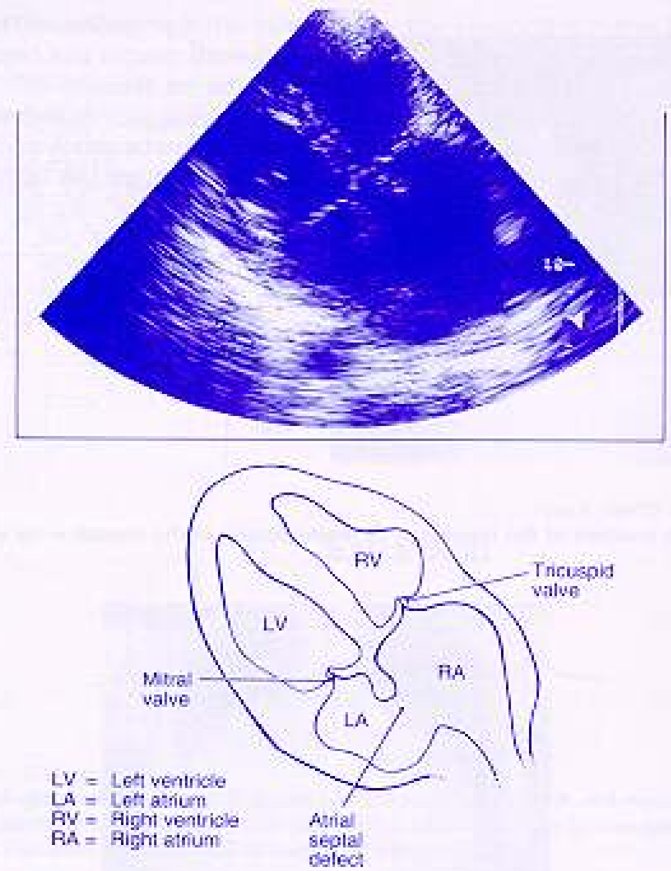
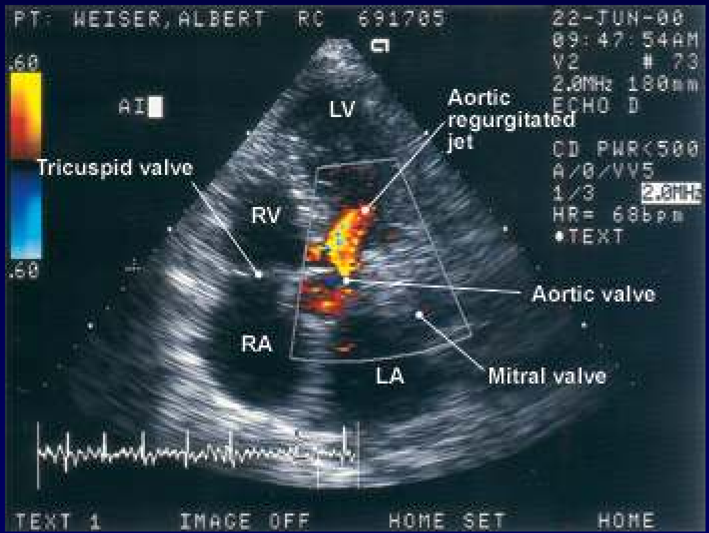


Figure 3. Echocardiogram

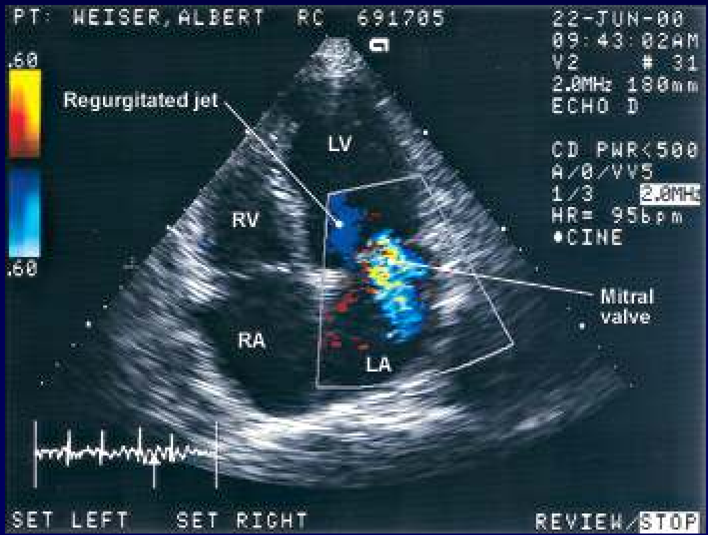
Notice the difference between an echocardiogram and the chest x-ray above. An echo shows the internal chambers of the heart. The heart in this picture has an atrial septal defect (hole between the two upper chambers). The image is upside down, so the abnormality appears to be in the lower half of the heart.

Ultrasound – Echo

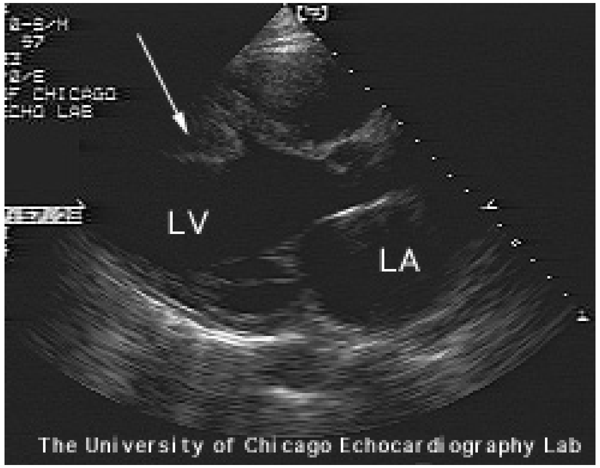
Aortal insuficiency/ regurgit.

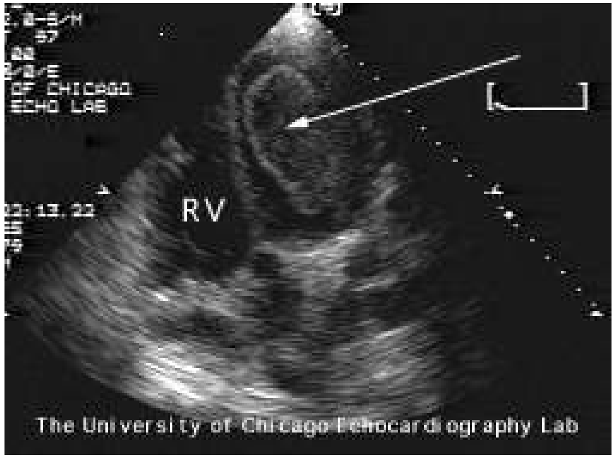


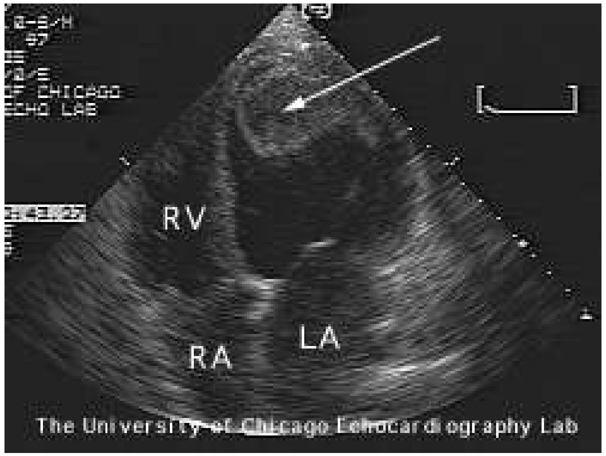
Mitral insuficiency/ regurgit.



Thrombus in Left Ventricle (Echocardigrafy)







occupies a substantial portion of the LV apex

Chest X-ray

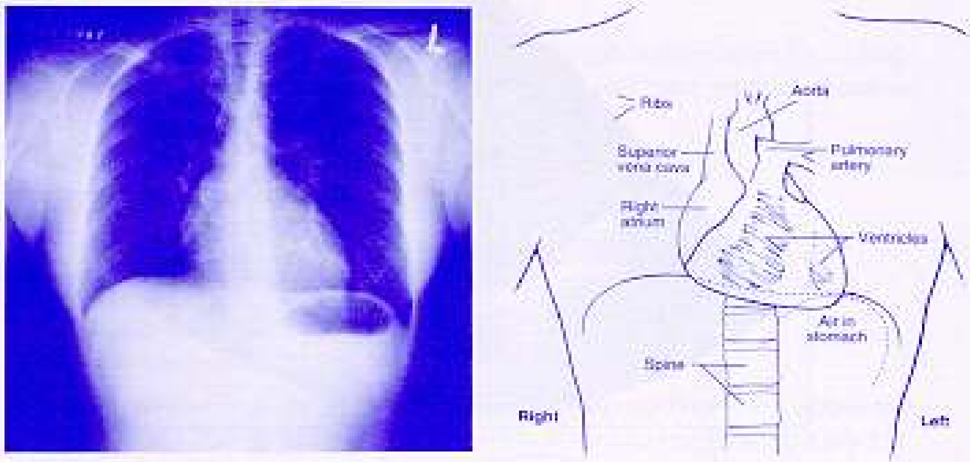


Figure 2.a Chest X-ray
Notice the position of the heart and its major vessels in the normal x-ray shown above.

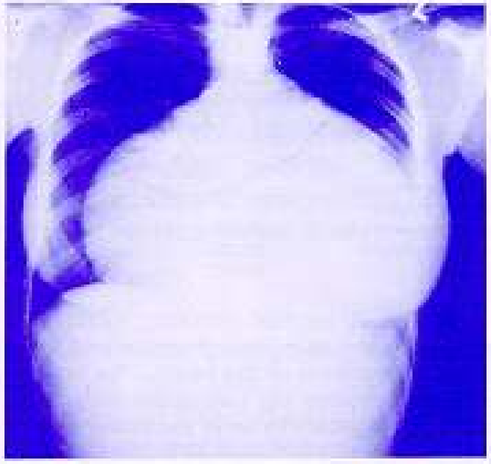
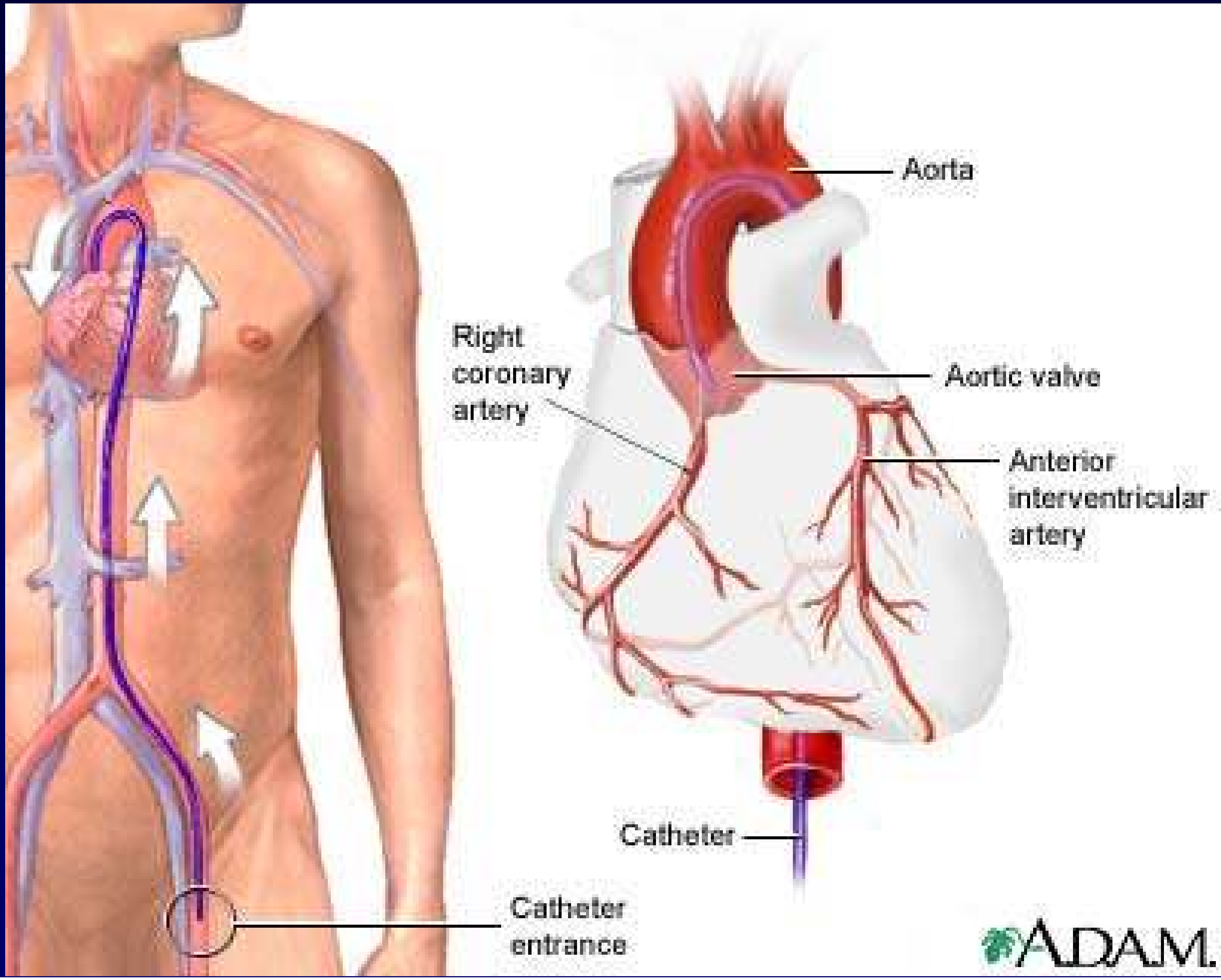
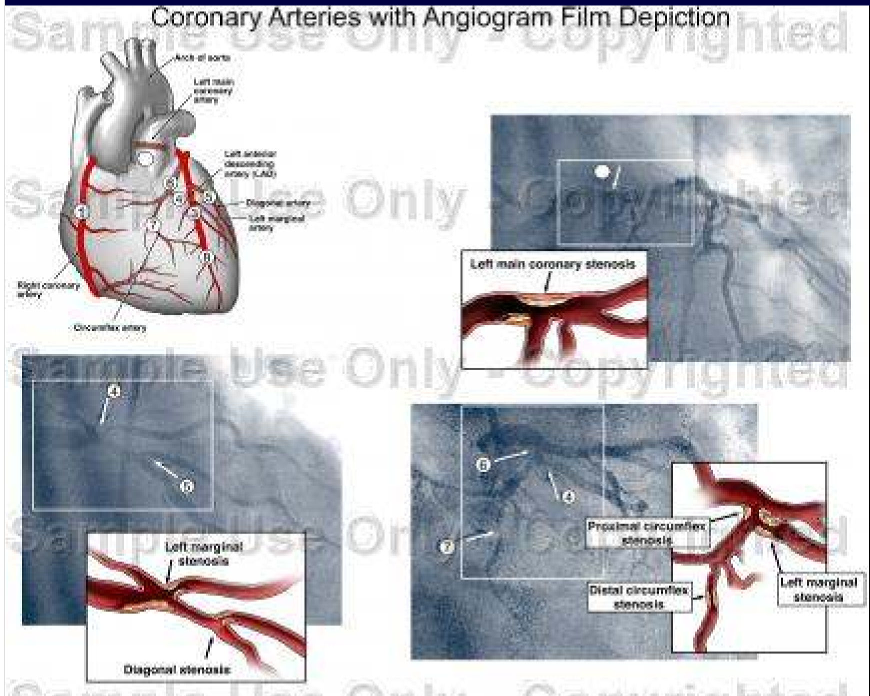


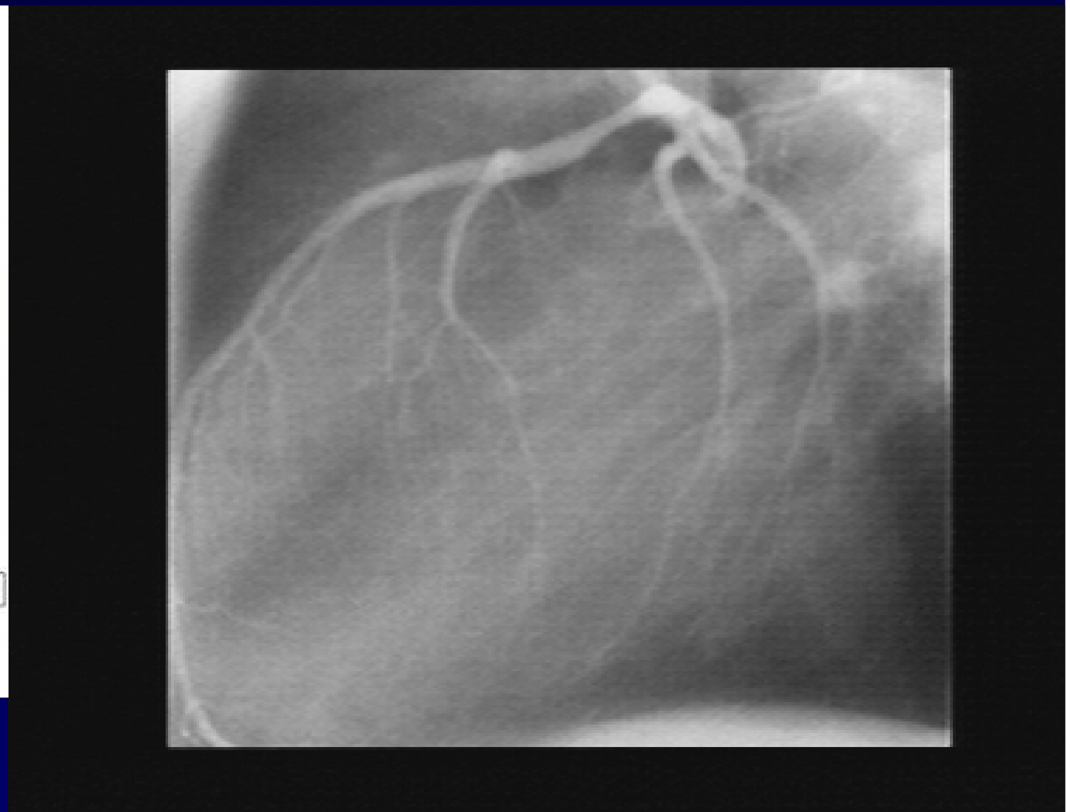
Figure 2.b
Compare this x-ray of an abnormally enlarged heart with the one above.

Coronaro-graphy



Coronarography





Coronarography

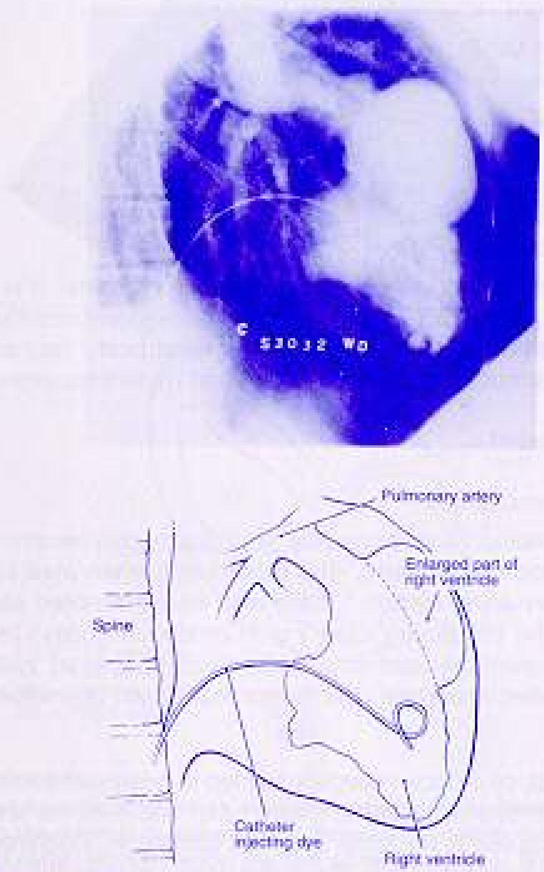


Figure 4. *Angiogram*
An angiogram is the picture produced by heart catheterization. The shape of the chambers and blood vessels is shown when dye is injected through the catheter. This picture shows an enlargement of the right ventricle. The catheter wire is also visible.

MRI

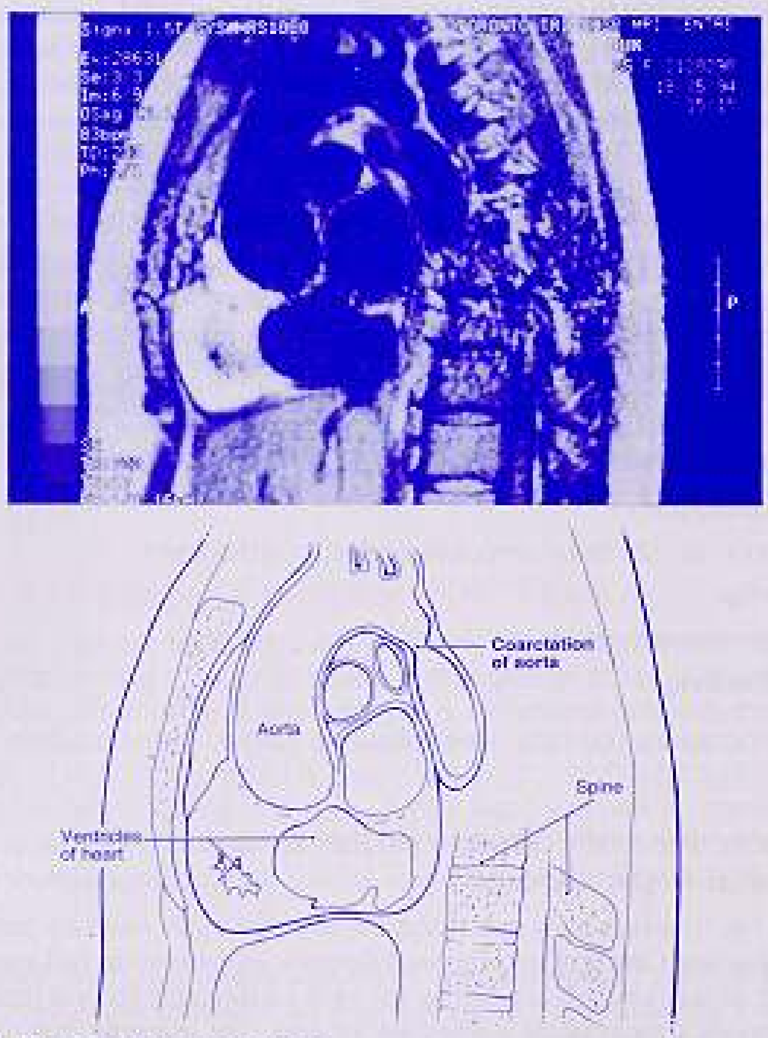


Figure 5. Magnetic Resonance Image
An MRI gives a highly detailed picture of the heart. In this picture you can see how the major blood vessel, the aorta, is 'pinched'. This is called *coarctation of the aorta.*

CT

During a computerized tomography (CT) scan, a thin X-ray beam rotates around an area of the body, generating a 3-D image of the internal structures

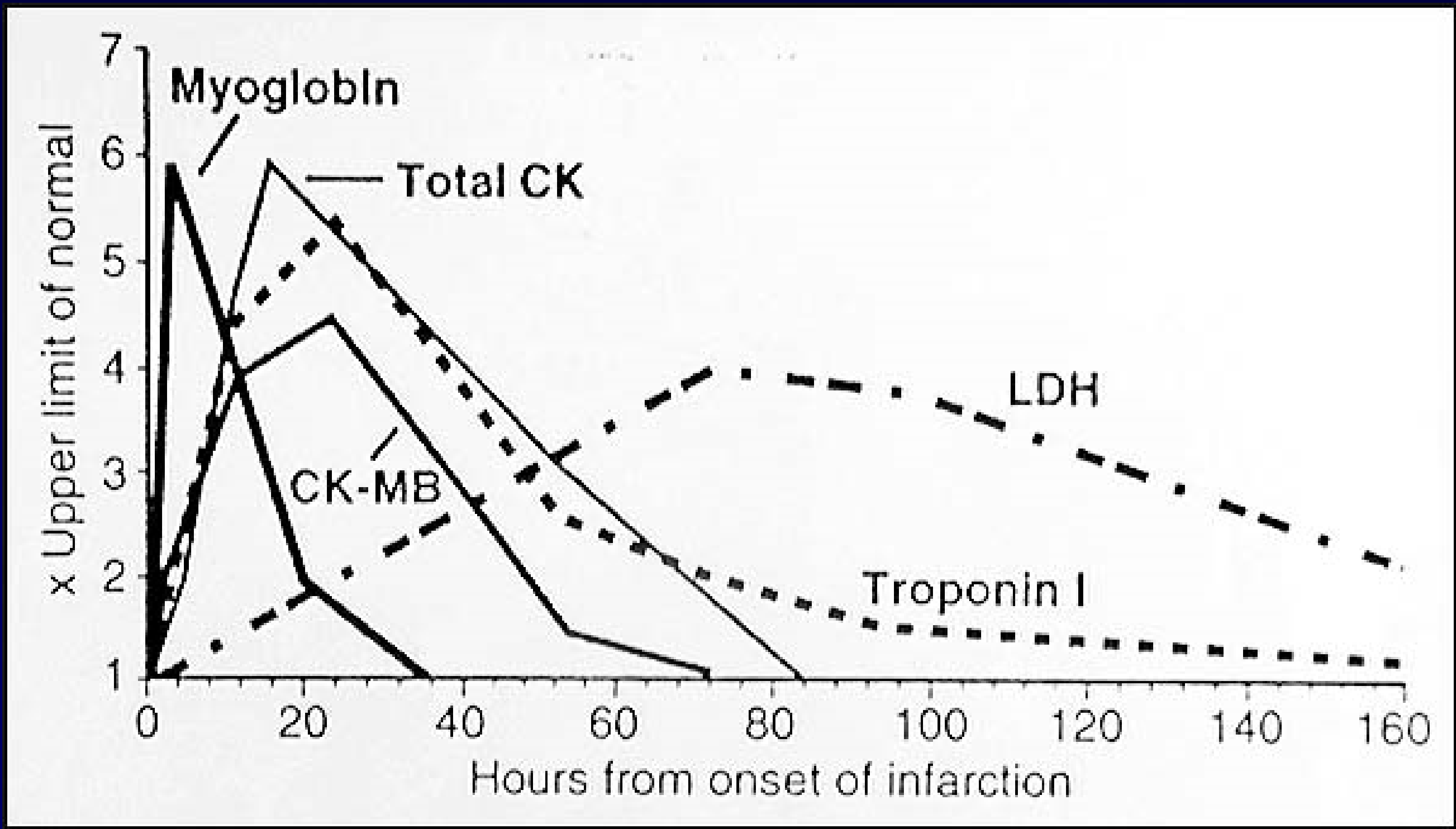
A.D.A.M.

Radioisotope imaging methods

- Perfusion Thallium scan (Tl^{201})
  - Thallium: enters intracellular compartments, kinetics comparable to Potassium
  - Diagnosis of ischemia

- Isotope ventriculography

Biochemical markers for acute myocardial infarction



Laboratory tests

Diagnosis of acute ***myocardial infarction***:
(*necrotic tissue and the reaction of the organismu*)
-CK-MB,
-AST,
-LD,
-myoglobin,
-troponins,
-leucocytes,
-FW

BNP (brain natriuretic peptide) in ***heart failure***

Fick principle

To measure oxygen consumption or cardiac output (CO)

$$\textbf{consumption } O_2 = \frac{\text{blood flow in the lung}}{\text{arterial } O_2 - \text{venous } O_2}$$

$$\textbf{CO} = \frac{\text{consumption of } O_2}{\text{AV difference}}$$

Example:

1 L of arter. blood contains cca 200 mL of oxygen, 1 L of mixed ven. blood 150 mL. AV difference is thus 50 mL/L of blood. These values can be determined by catheterization and oxygen measurment.

Oxygen consumption in 1 min is 250 mL (measurement of estimation, e.g. 3 mL O_2/min/kg or 125 mL/min/m^2).

CO is in this case 250/50, i.e. 5 L per minute.

$$VO_2 = VE \times (FiO_2 - FeO_2)$$

VE – minute ventilation
Fi – inspiratory fraction
Fe – exspiratory fraction

Pathophysiology of Cardiovascular system

- Hypertension
- Ischemia
- Arhythmia
- Diseases of endo-, myo-, peri-cardium
- Valve diseases and inherited cardiac defects

Symptoms of Cardiovascular Diseases

Chest pain or discomfort

Dyspnea (abnormally uncomfortable awareness of breathing)

Palpitations (uncomfortable awareness of beating of the heart)

Syncope

Peripheral edema

Claudication

Examinations in Cardiology I - Hemodynamics

Disclaimer – this is not an official study material, use it at your own risk…